



Arnold Schwarzenegger
Governor

CERTS MICROGRID LABORATORY TEST BED

Tecogen 60kW Inverter-Based
CHP Modules Factory Testing

APPENDIX D

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Prepared By:
Lawrence Berkeley National Laboratory

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Prepared By:
Lawrence Berkeley National Laboratory
Joseph H. Eto, Principal Investigator
Berkeley, CA 94720
Jean Roy, Tecogen, Inc.
Robert Lasseter, University of Wisconsin-Madison

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Prepared For:
Public Interest Energy Research (PIER)
California Energy Commission

Bernard Treanton
Contract Manager

Mike Gravely
Program Area Lead
ENERGY SYSTEMS INTEGRATION

Mike Gravely
Office Manager
ENERGY SYSTEMS RESEARCH



Martha Krebs, Ph.D.
PIER Director

Thom Kelly, Ph.D.
Deputy Director
ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones
Executive Director

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TECOGEN 60 kW Inverter-Based CHP Modules

CERTS Microgrid Test Bed Project

Tecogen Factory Testing
Unit Serial #200835

3/15/06

Introduction

This report presents the factory test data of the first Tecogen CHP unit (Serial # 200835), equipped with a customized inverter (by Youtility) that is configured with the CERTS microgrid control algorithm. Figure 1 presents a one-line diagram of the test set-up. The unit generates power in a stand-alone mode (no grid-tie) and is connected to a load bank. The output of the inverter is connected to the Delta side of a transformer in a 3-wire configuration. The output of the transformer is wired to the load bank in a 4-wire configuration with a 25-yard loop.

The inverter is also equipped with a Surge Module wired directly to the DC Bus. The Surge Module is a battery powered energy storage device with a rating of 20 kW for 3 seconds. Its purpose is to assist the engine/inverter's response to step loads. It is housed separately in an adjacent cabinet (DC power wiring length: 12.5 feet).

All testing was done with the inverters set to Power Control Mode.

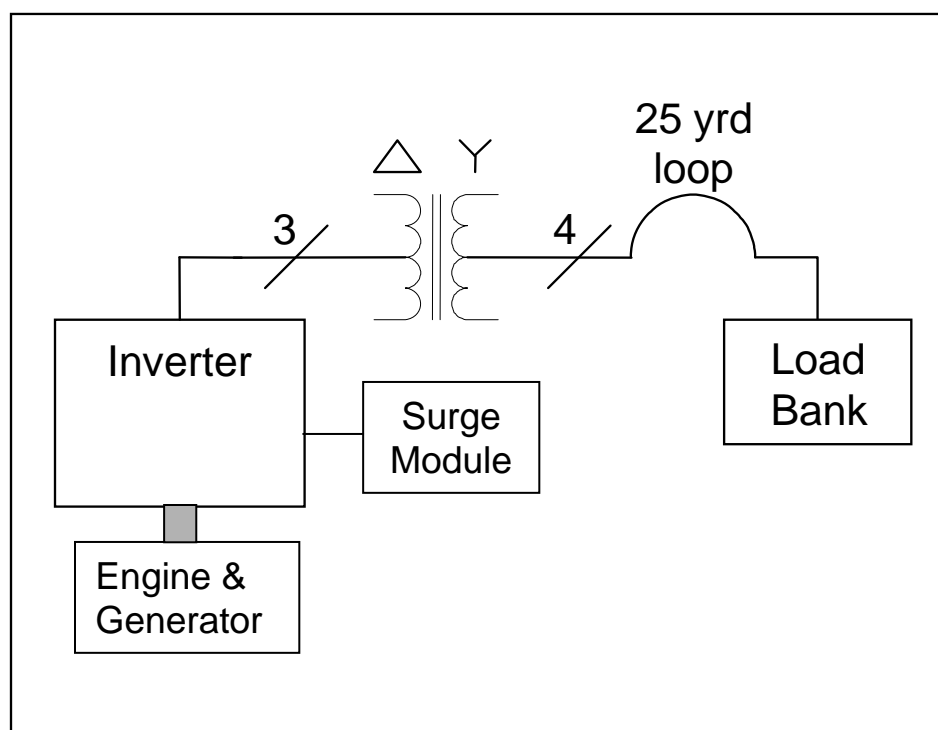


Figure 1 Factory Test One-line Diagram

B.2. Step Load Evaluations with Surge Module – Variable Speed Operation

The following step loads were tested:

	Test Plan	Actual Test Point	Comments
i.	0-30 kW	0 – 30 kW	
ii.	0 – 60 kW	0 – 50 kW	Engine stalls at a step load of 0 – 55 kW in this variable speed mode. A 0 – 60 kW step load can be achieved at fixed speed (see section B.3). Minimum engine speed will be raised in testing of Unit #2 to 1560 rpm (52 Hz) in order to achieve 0 – 60 kW in variable speed mode with the surge module.
iii.	15 – 45 kW	15 – 50 kW	A 15 – 50 increment was easier to implement with the load bank.
iv.	30 – 60 kW	30 – 55 kW	As was done in Phase 1 at Youtility, 55 kW was done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
v.	60 – 0 kW	60 – 0 kW	
vi.	30 – 0 kW	30 – 0 kW	

Table 1: Test Point Summary – Step Loads with Surge Module/Variable Speed

For each step load point, an oscilloscope trace was captured that measured the power output, frequency, voltage, and current. These measurements were taken on the microgrid side (Y side) of the transformer. In each plot the data is formatted in the following way:

Ch1 = Unit RMS Power Output;

0.0V = -15KW

0.5V = 0KW

1.5V = 30KW

2.5V = 60KW

Ch2 = Unit Operating Frequency;

60Hz --> 2.3V

59.5Hz --> 1.66V

60.5Hz --> 2.94V

Ch 3 – The graphical trace is Grid Voltage L-N, nominal 277 Volts. The displayed value on right hand side is the measured frequency after the step load.

Channel 4

Ch4 = Unit Output Current; 1V = 100Amps

Also, the Step “Up” load points (i-iv.) were run two separate times so that additional data on the system dynamics, with the surge module, could be captured. This oscilloscope data is formatted as follows:

Channel 1 = Engine RPM;

120 Hz (3600 rpm) per 3.3 volts

1 volt per division

Zero point is at black “1” marker on left-hand side of Figure

Nominal Minimum Speed = 50 Hz (1500 rpm)

Channel 2 = Bus Voltage

Zero point is actually 500 volts and measures from black “1” marker on left-hand side of Figure

100 volts per division

Nominal Voltage; 860 volts

Channel 3 = AC Current ; 1 V = 100 amps

Channel 4 = Surge Module Current

10 mV = 20 amps

10 mV per division

Nominal Current; 26 amps

The results of each test is organized in a table that defines the load setpoint (abbreviated S.P) and the actual power output from the unit. The table also contains the microgrid operating frequency before and after the transient event occurs (These frequency values are obtained from the units software and not the oscilloscope measurement). Data contained in column A defines the operating condition and the state of the microgrid before the transient condition being tested occurs. Data contained in column B defines the operating condition and the state of the microgrid after the transient condition being tested has occurred.

i. Step Load Evaluation 1

1.Load Bank Start Load = 0 kW

2.Unit A CMD = 20 kW

3.Load Bank End Load = 30 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/30.45 kW
Frequency Hz	60.16 Hz	59.91 Hz

Table 2 Step Load Evaluation 1: 0 – 30 kW (w/Surge Module)

0 – 30 KW Step Load –Surge Module- Variable Speed

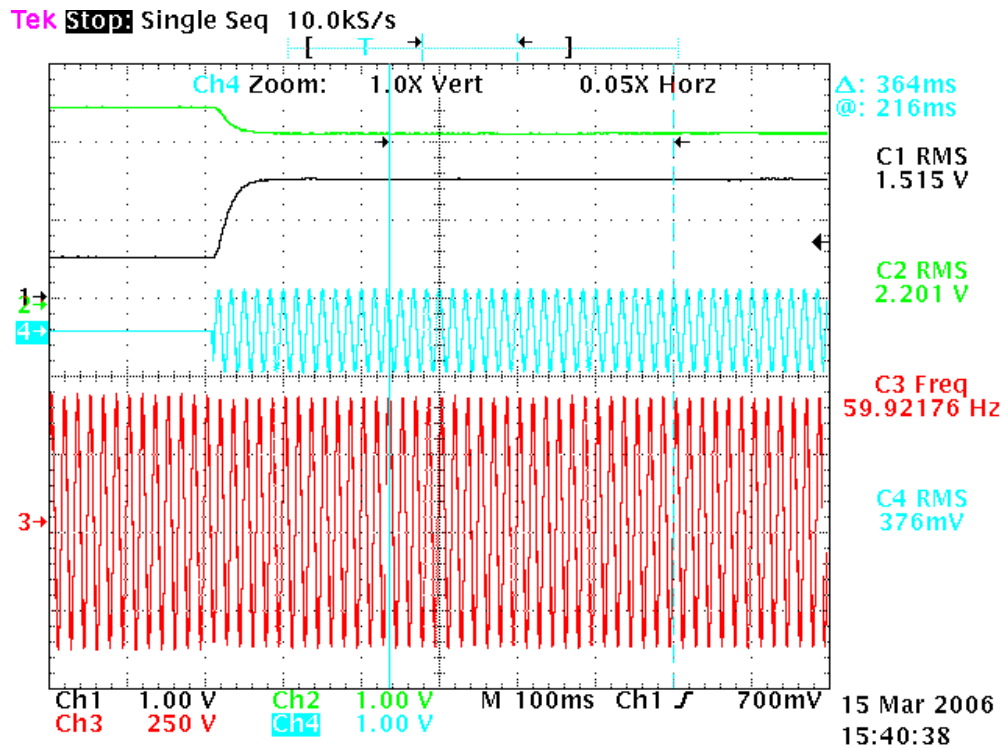


Figure 2 0 –30 kW: Power, Frequency, Voltage, Current

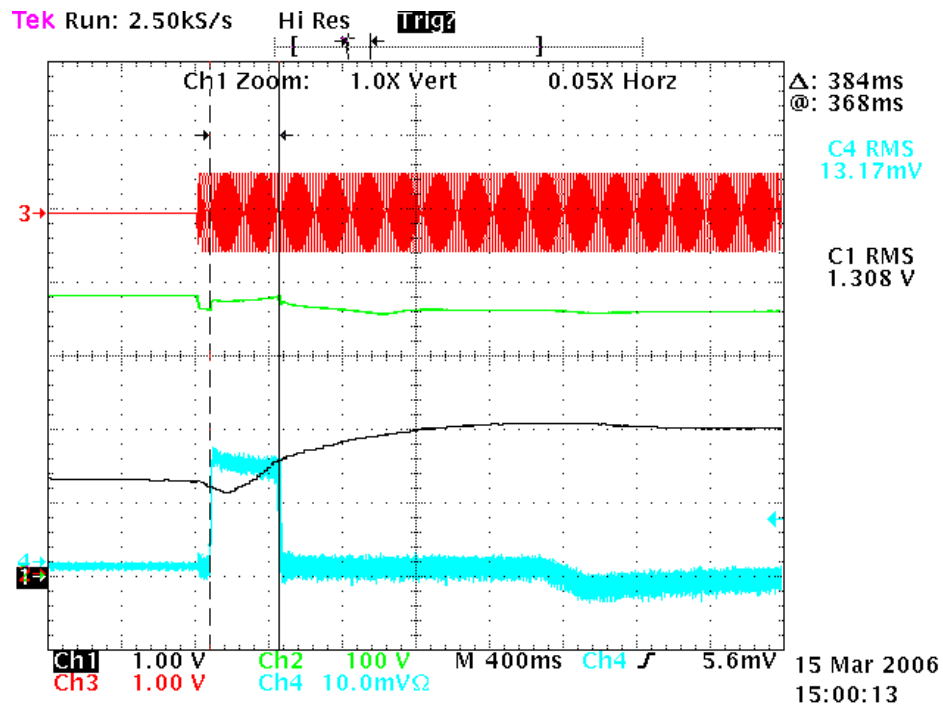


Figure 3 0 – 30 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

ii. Step Load Evaluation 2

1. Load Bank Start Load = 0KW
2. Unit A CMD = 20KW
3. Load Bank End Load = 60KW (Engine Stalled)
Load Bank End Load = 55 kW (Engine Stalled)
Load Bank End Load = 50 kW (Okay)

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/50.97 kW
Frequency Hz	60.16 Hz	59.75 Hz

Table 3 Step Load Evaluation 2: 0 – 60 kW (w/Surge Module)

0 – 50 kW Step Load –Surge Module- Variable Speed

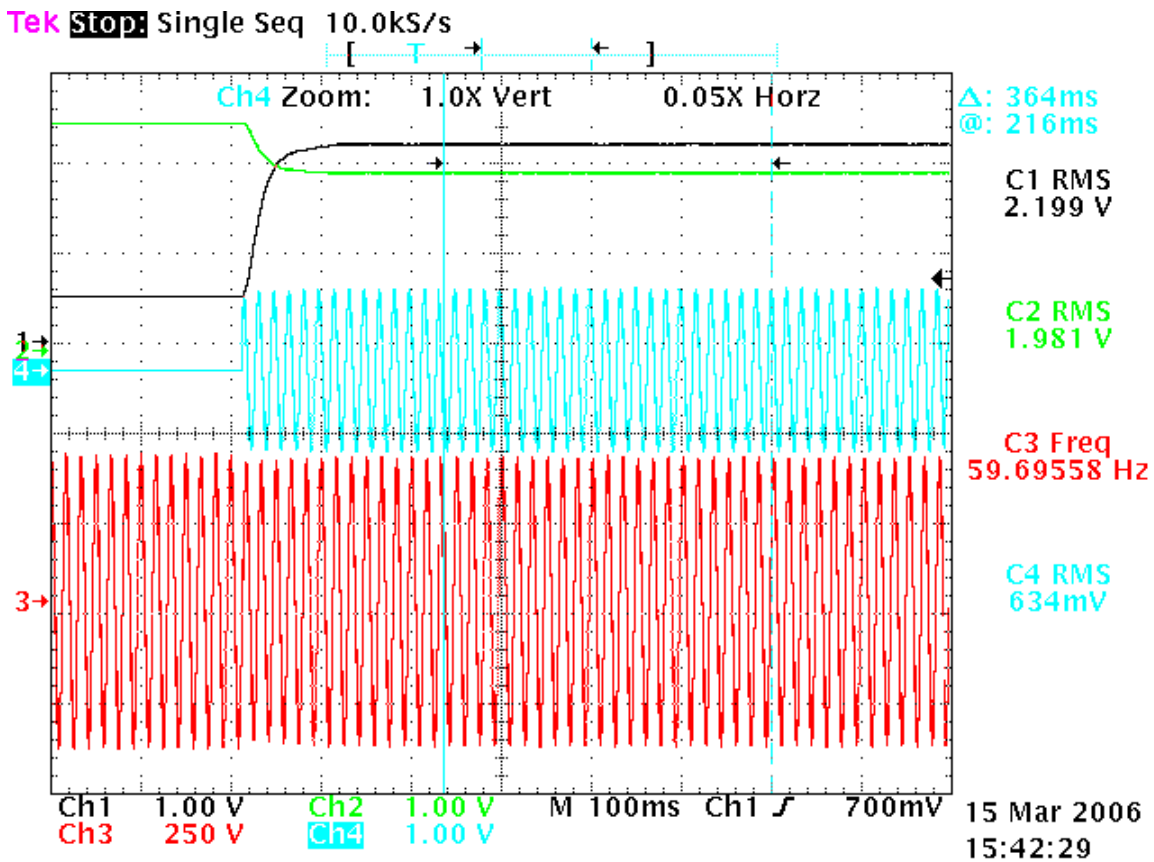


Figure 4 0 –50 kW: Power, Frequency, Voltage, Current

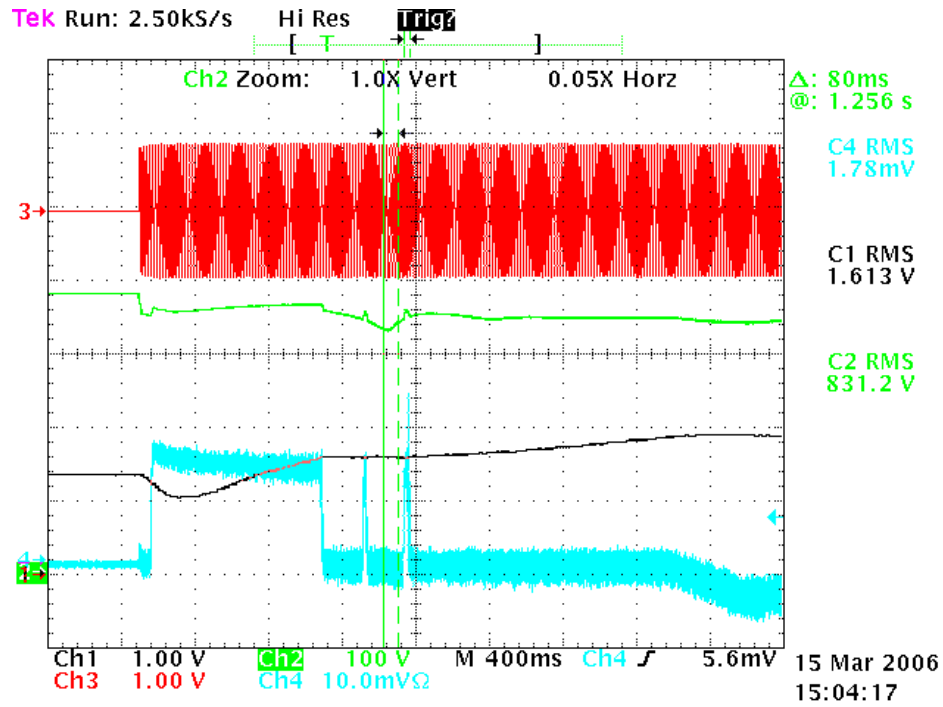
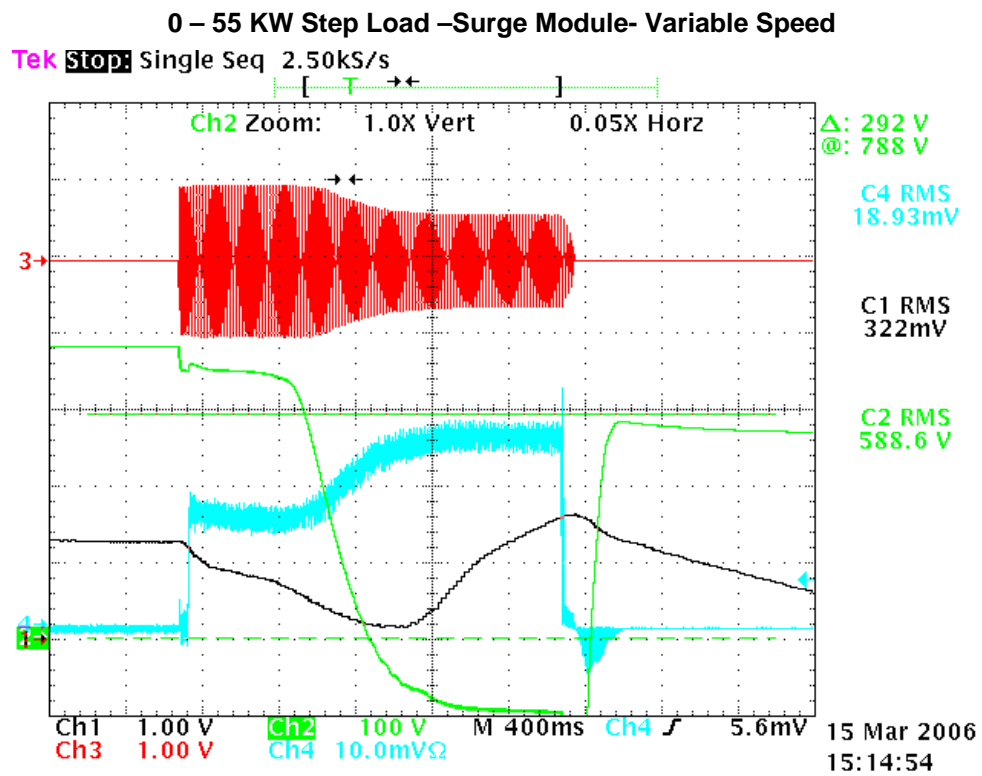


Figure 5 0 – 50 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current



Engine Stalled

Figure 6 0 – 55 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

iii. Step Load Evaluation 3

1. Load Bank Start Load = 15 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 50 kW (Changed from 45 kW because easier to implement on Load Bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/49.86 kW
Frequency Hz	60.16 Hz	59.75 Hz

Table 4 Step Load Evaluation 3: 15 – 50 kW (w/Surge Module)

15 – 50 KW Step Load –Surge Module- Variable Speed

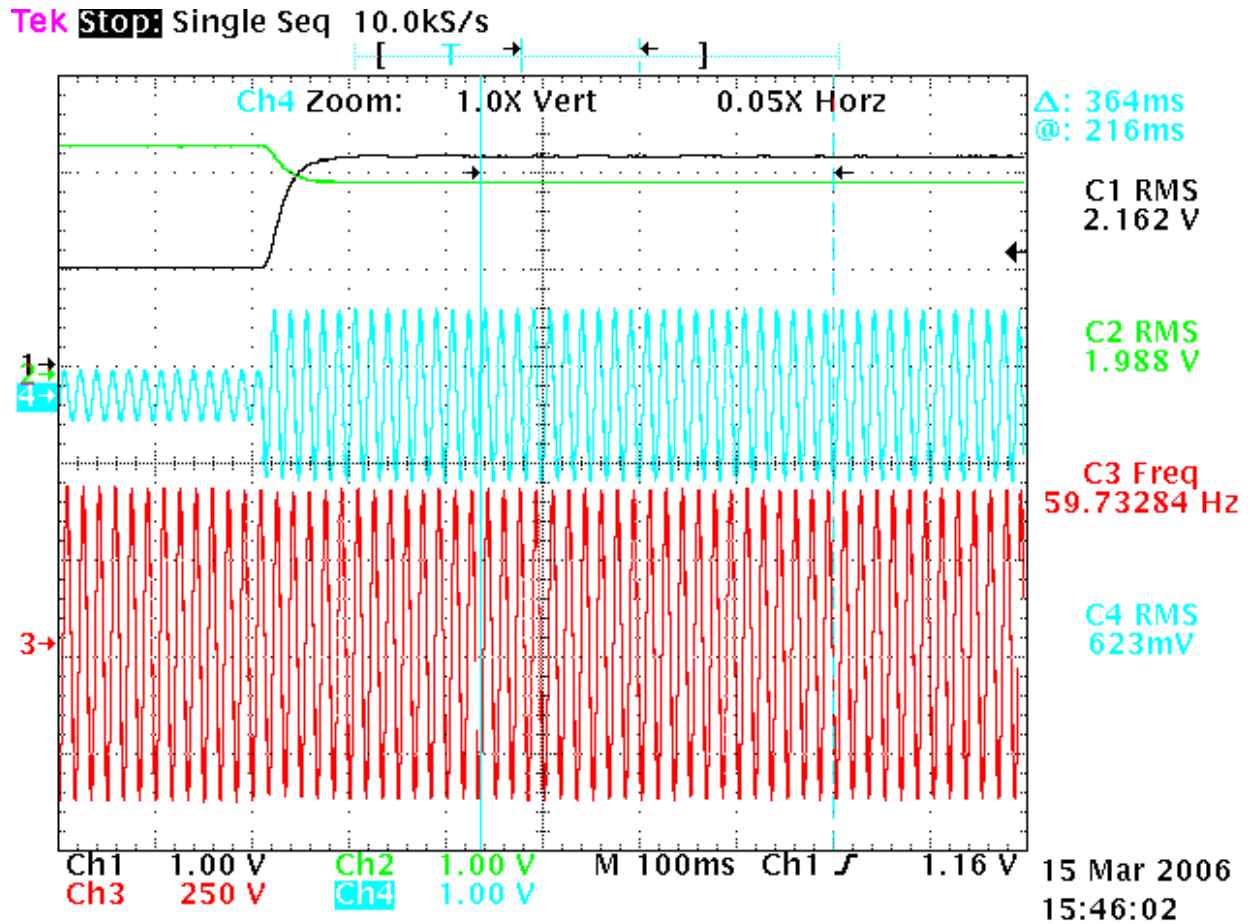


Figure 7 15 – 50 kW: Power, Frequency, Voltage, Current

15 – 50 KW Step Load –Surge Module- Variable Speed

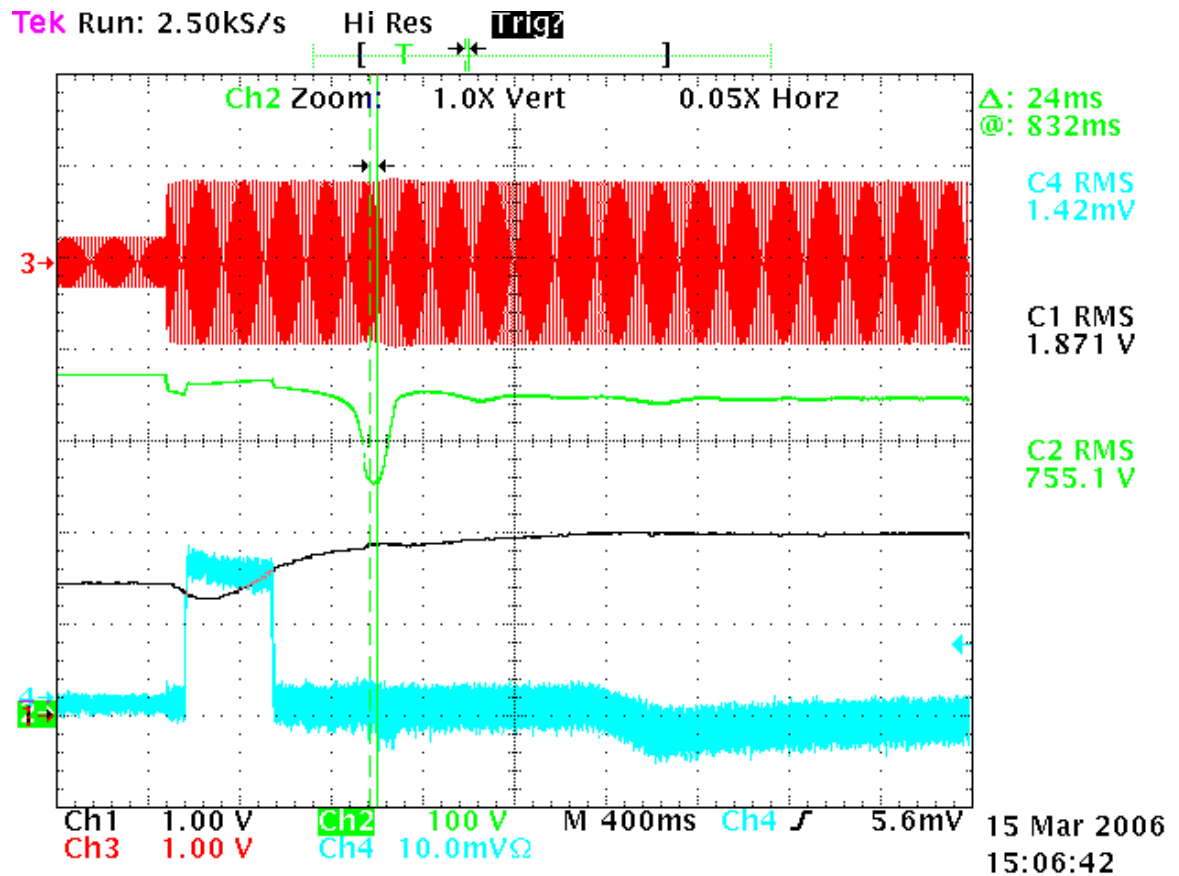


Figure 8 15 – 50 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

- iv. Step Load Evaluation 4
- 1.Load Bank Start Load = 30 kW
 - 2.Unit A CMD = 20 kW
 - 3.Load Bank End Load = 55 kW

	A	B
Unit #1 (S.P/Actual) KW	20.0/0.0 kW	20.0/55.5 kW
Frequency Hz	60.16 Hz	59.70 Hz

Table 5 Step Load Evaluation 4: (30 – 55 kW) (w/Surge Module)

30– 55 KW Step Load –Surge Module- Variable Speed

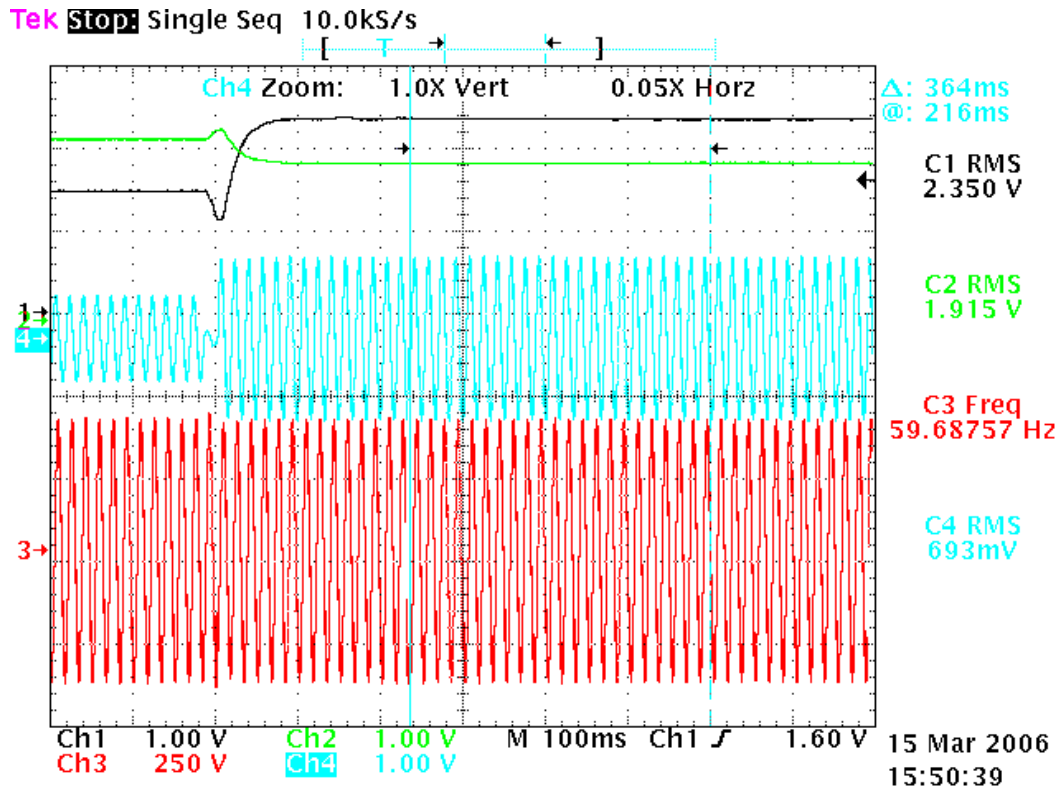


Figure 9 30 – 55 kW Power, Frequency, Voltage, Current

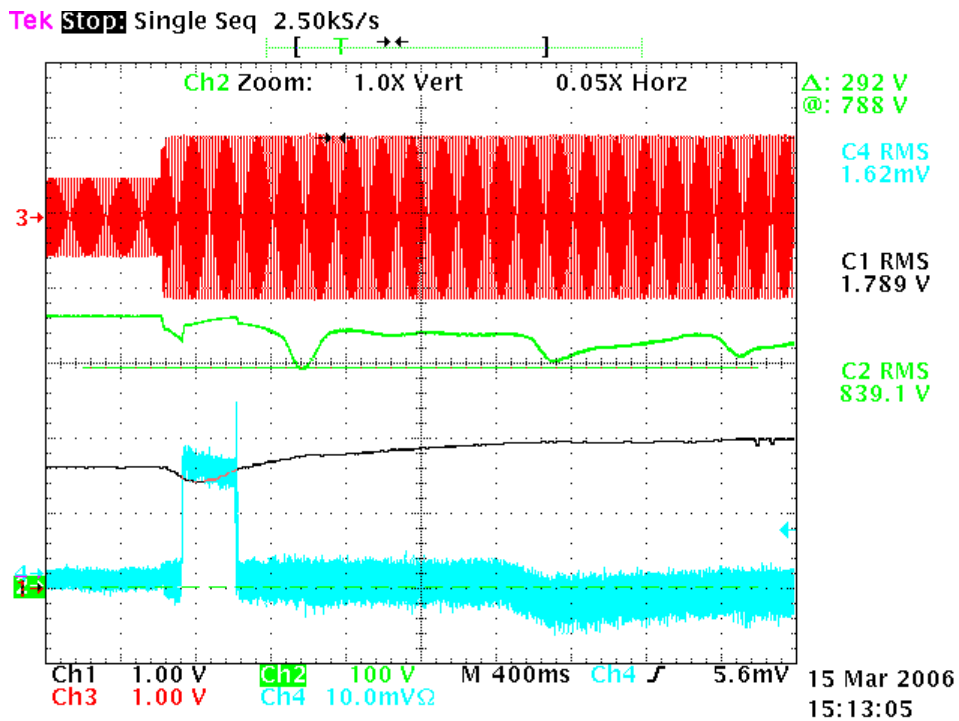


Figure 10 30 – 55 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

v. Step Load Evaluation 5

- 1.Load Bank Start Load = 60 kW
- 2.Unit A CMD = 20 kW
- 3.Load Bank End Load =0 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/60 kW	20.0/0 kW
Frequency Hz	59.67 Hz	60.6 Hz

Table 6 Step Load Evaluation 5: 60 – 0 kW (w/Surge Module)

60– 0 kW Step Load –Surge Module- Variable Speed

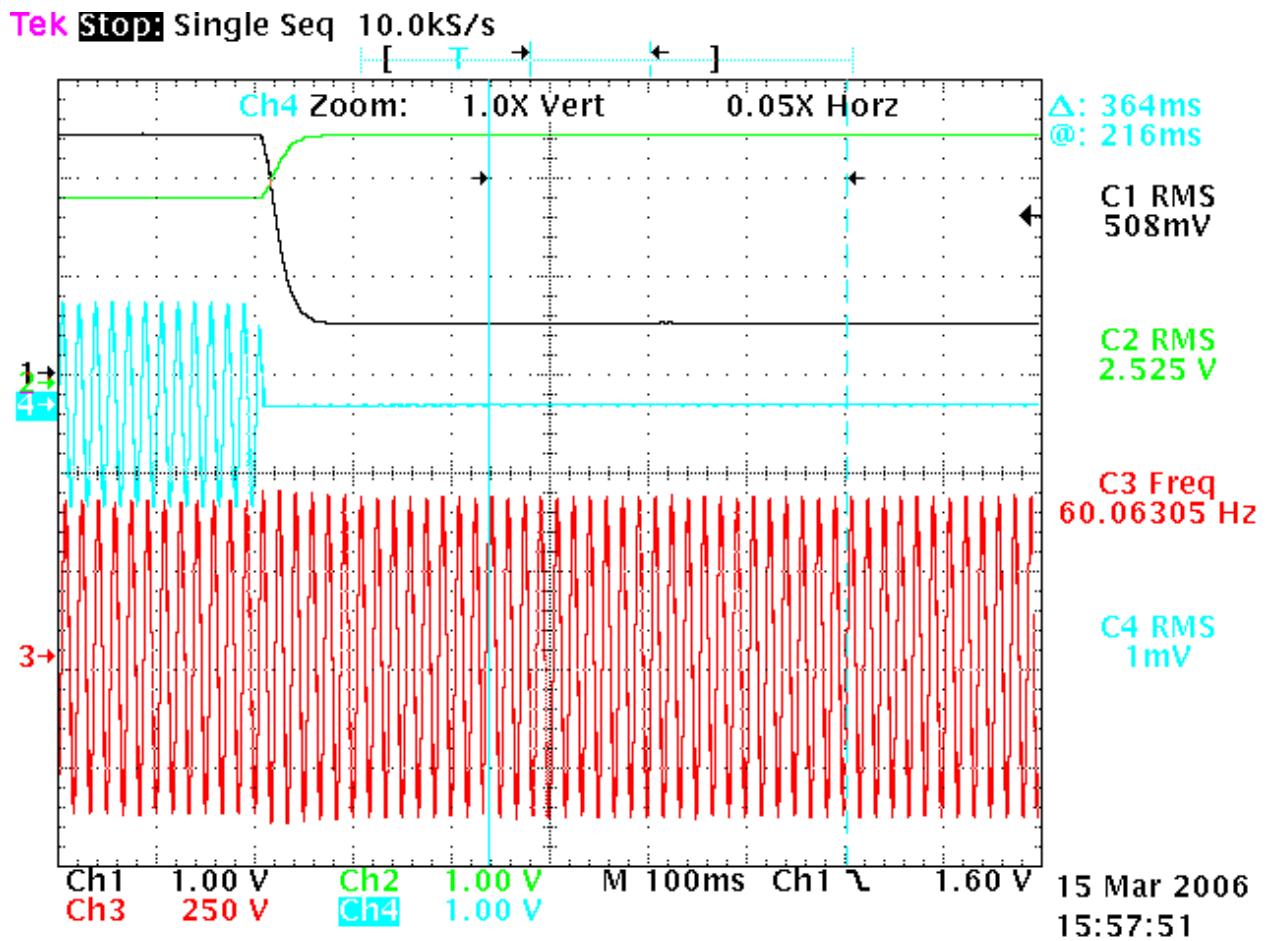


Figure 11 60-0 kW: Power, Frequency, Voltage, Current

vi. Step Load Evaluation 6

1. Load Bank Start Load = 30 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 0 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/30 kW Unit	20.0/0 kW
Frequency Hz	59.91 Hz	60.16 Hz

Table 7 Step Load Evaluation 6: 30 – 0 kW (w/Surge Module)

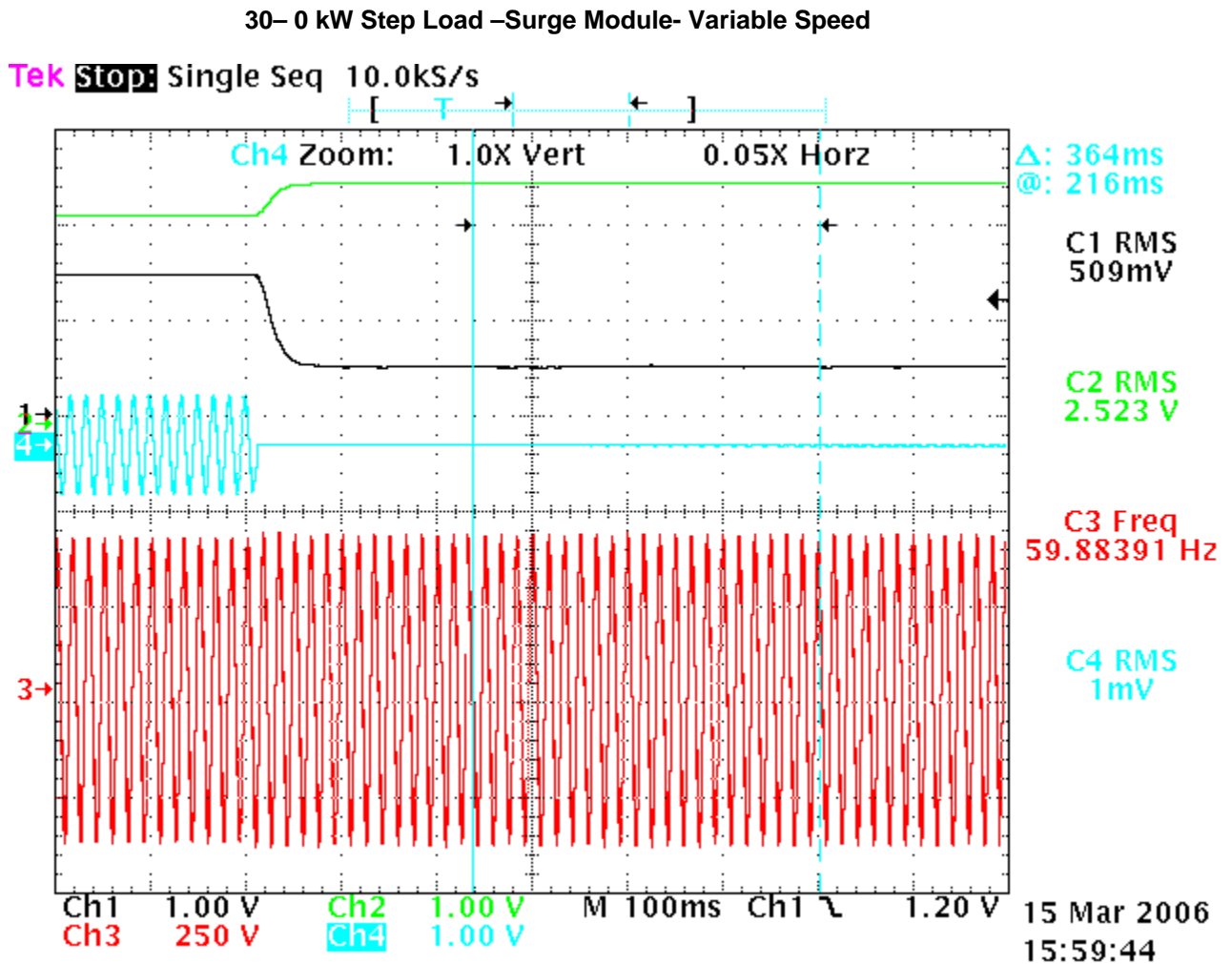


Figure 12 30 – 0 kW Power, Frequency, Voltage, Current

B.3. Step Load Evaluations without Surge Module – Fixed Speed Operation

The CHP unit was tested with the surge module disabled. The results showed that the dynamics of the engine/inverter could successfully handle a step load without the surge module. However, the engine must operate at a fixed speed and there is a minimum engine operating speed for each load step to prevent the engine from stalling. This minimum speed was determined for each “step-up” load.

The following table summarizes the test results. The minimum operational speed required for the given step load is highlighted with a bold box.

Fixed Engine Speed – No Surge Module			
Step Loads	Engine Speed [Hz]	Engine Speed [RPM]	Pass/Fail
0 - 30	65	1950	Pass
	60	1800	Fail
0 - 60	72	2160	Pass
	70	2100	Pass
	68	2040	Fail
15 - 50	68	2040	Pass
	66	1980	Pass
	65	1950	Pass
	64	1920	Pass
	63	1890	Pass
	62	1860	Pass
	61	1830	Pass
	60	1800	Fail
30 - 60	70	2100	Pass
	68	2040	Pass
	67	2010	Pass
	66	1980	Pass
	65	1950	Pass
	64	1920	Pass
	63	1890	Fail

Table 8 Test Point Summary – Step Loads without Surge Module/Fixed Speed

i.) Step Load Evaluation 1

1. Load Bank Start Load = 0 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 30 kW

Engine Speed: 1950 rpm (65 Hz)

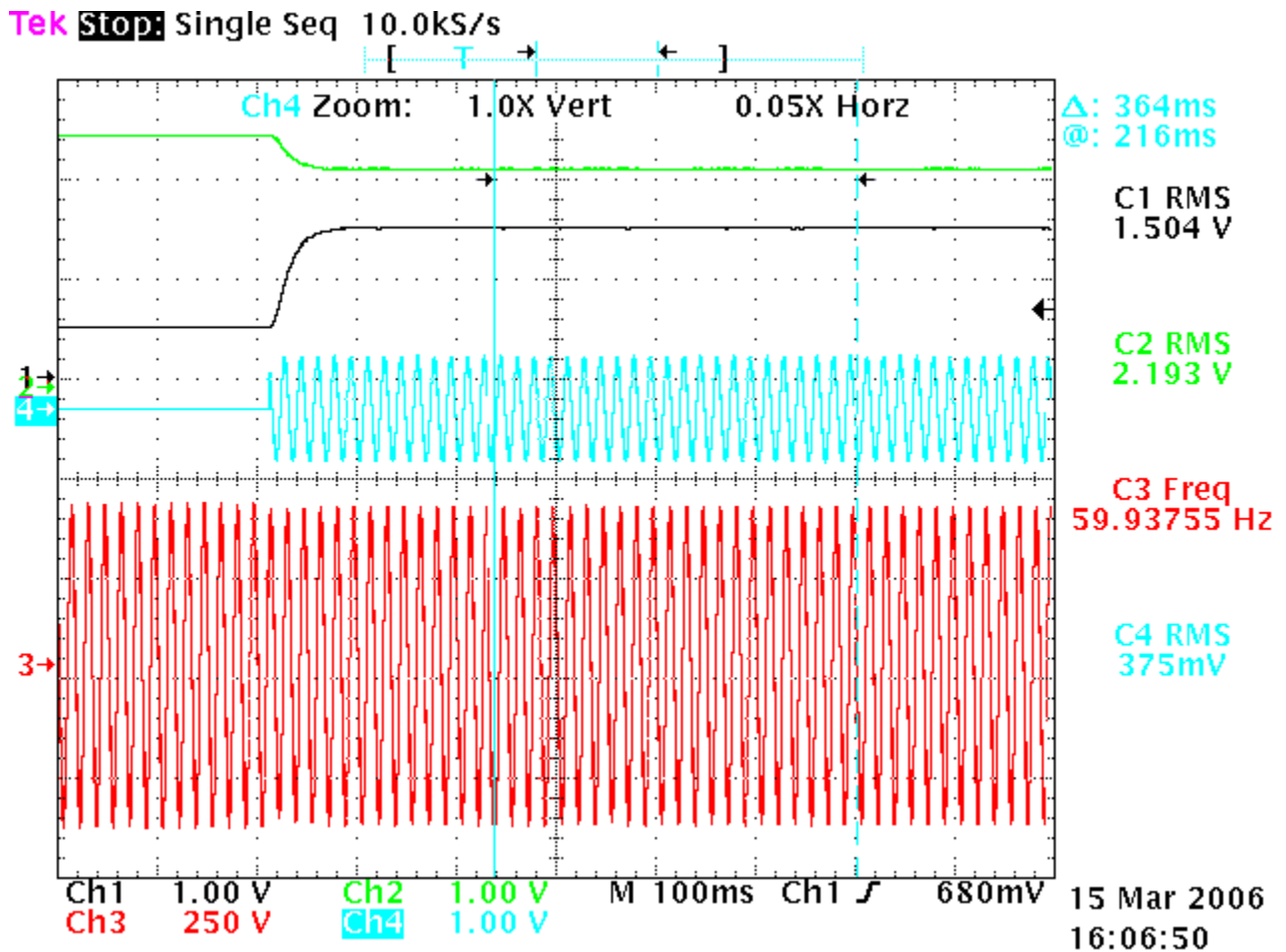


Figure 13 0-30 kW (Fixed Speed): Power, Frequency, Voltage, Current

- ii.) Step Load Evaluation 2
 4. Load Bank Start Load = 0 kW
 5. Unit A CMD = 20 kW
 6. Load Bank End Load = 60 kW

Engine Speed: 2160 rpm (72 Hz)

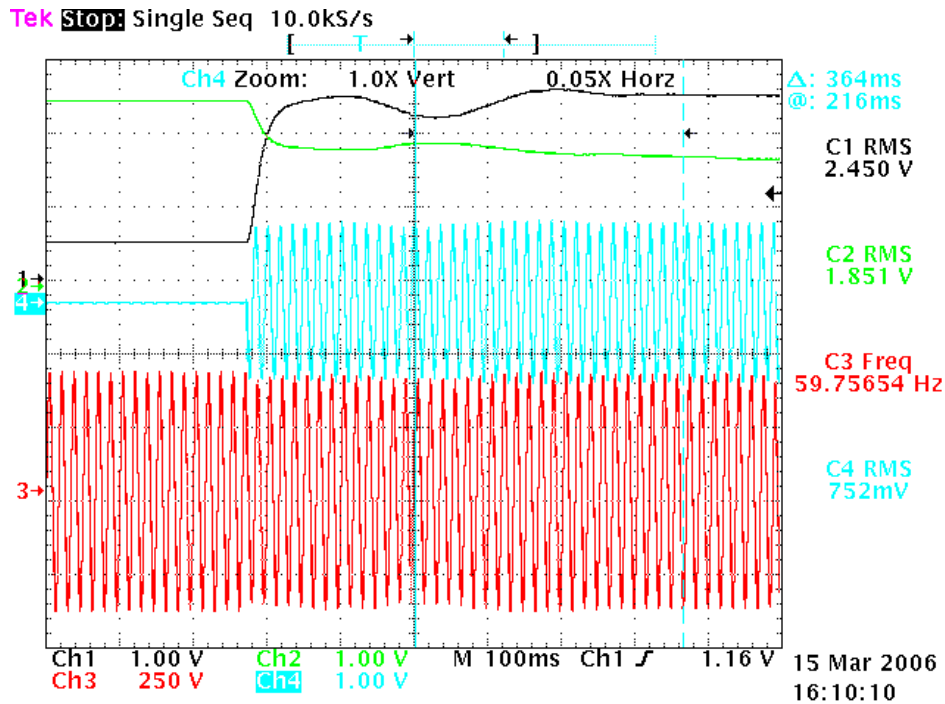


Figure 14 0 – 60 kW (Fixed Speed – 2160 rpm) Power, Frequency, Voltage, Current

Engine Speed: 2100 rpm (70 Hz)

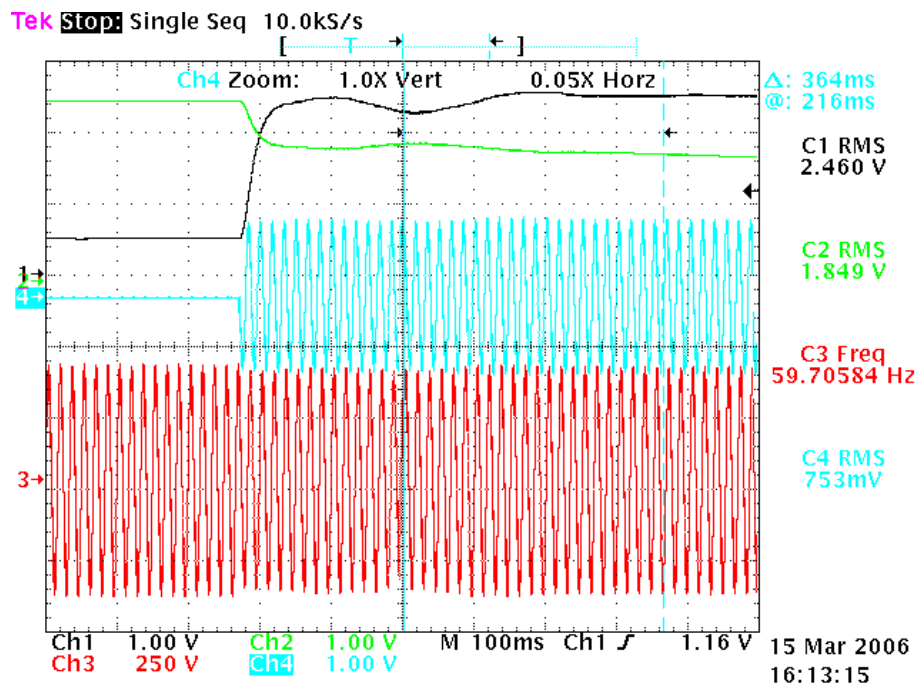


Figure 15 0 – 60 kW (Fixed Speed – 2100 rpm) Power, Frequency, Voltage, Current

iii.) Step Load Evaluation 3

1. Load Bank Start Load = 15 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 50 kW (Changed from 45 kW because easier to implement on Load Bank)

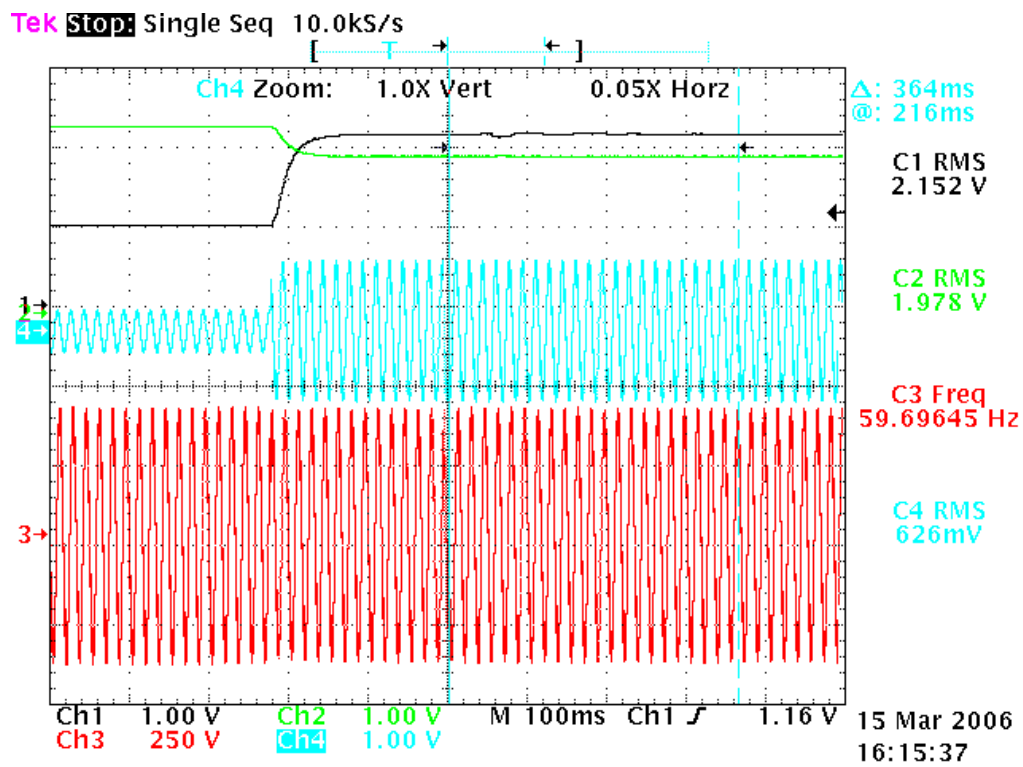


Figure 16 15 – 45 kW (Fixed Speed) Power, Frequency, Voltage, Current

iv.) Step Load Evaluation 4

1. Load Bank Start Load = 30 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 60 kW

Engine Speed: 2100 rpm (70 Hz)

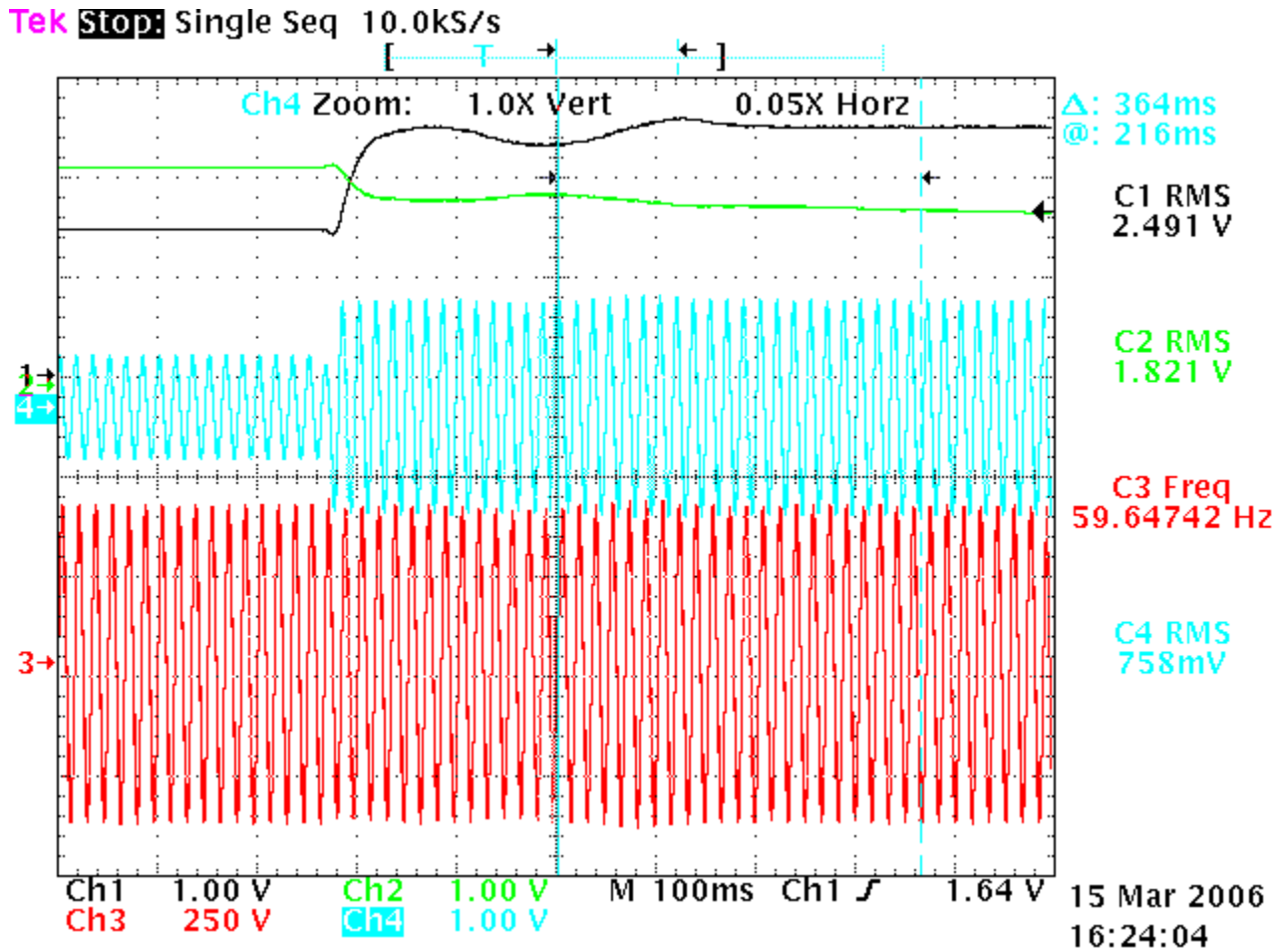


Figure 17 30 – 60 kW (Fixed Speed) Power, Frequency, Voltage, Current

**TECOGEN 60 kW
Inverter-Based CHP Modules**

CERTS Microgrid Test Bed Project

Tecogen Factory Testing
Unit Serial #200836

4/13/06

Introduction

This report presents the factory test data of the first Tecogen CHP unit (Serial # 200836), equipped with a customized inverter (by Youtility) that is configured with the CERTS microgrid control algorithm. Figure 1 presents a one-line diagram of the test set-up. The unit generates power in a stand-alone mode (no grid-tie) and is connected to a load bank. The output of the inverter is connected to the Delta side of a transformer in a 3-wire configuration. The output of the transformer is wired to the load bank in a 4-wire configuration with a 25-yard loop.

The inverter is also equipped with a Surge Module wired directly to the DC Bus. The Surge Module is a battery powered energy storage device with a rating of 20 kW for 3 seconds. Its purpose is to assist the engine/inverter's response to step loads. It is housed separately in an adjacent cabinet (DC power wiring length: 12.5 feet).

All testing was done with the inverters set to Power Control Mode.

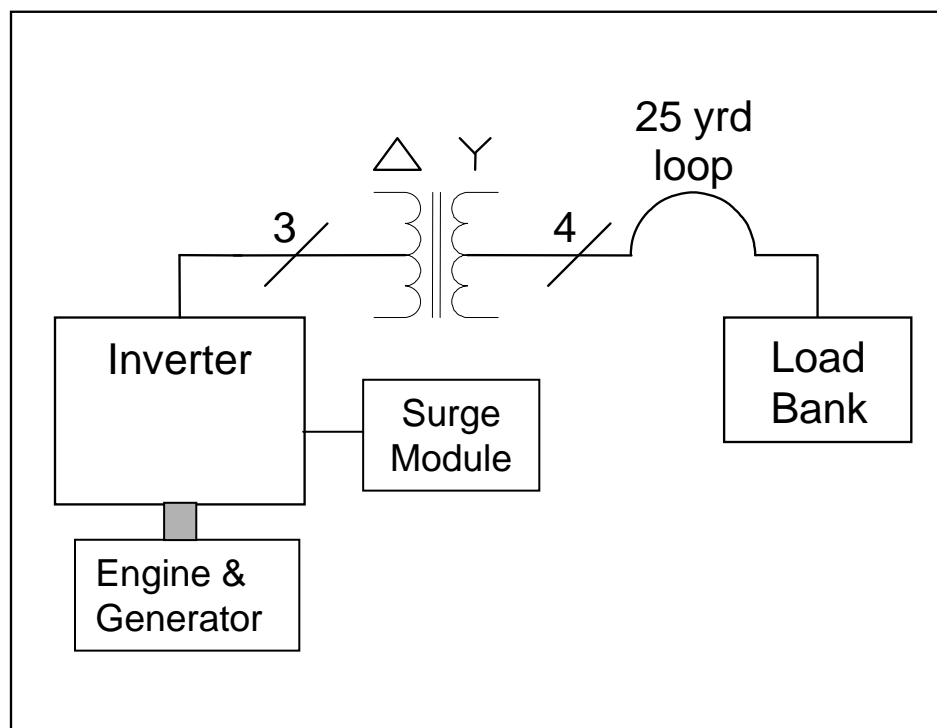


Figure 18 Factory Test One-line Diagram

B.2. Step Load Evaluations with Surge Module – Variable Speed Operation

In prior testing on Unit# 200835, it was determined that with a minimum speed setting of 1500 rpm (50 Hz), the system could not achieve the 0 – 60 kW step load. The objective for testing this second unit was to raise the minimum engine speed in Variable Speed mode to a level that would successfully accomplish the 0 – 60 kW step load. This would then establish the lower speed limit for Variable Speed operation. This speed was determined to be 1800 rpm (60 Hz). Therefore, all data was taken with the following settings in the software:

Minimum Engine Speed: 60 Hz (1800 rpm)

Maximum Engine Speed: 72 Hz (2160 rpm)

The following step loads were tested :

	Test Plan	Actual Test Point	Comments
i.	0-30 kW	0 – 30 kW	
ii. a		0 – 50 kW	Done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
ii. b	0 – 60 kW	0 – 60 kW	
iii.	15 – 45 kW	15 – 50 kW	Changed to 50 kW because easier to implement on load bank
iv. a		30 – 55 kW	Done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
iv. b	30 – 60 kW	30 – 60 kW	
v. a	60 – 0 kW	60 – 0 kW	
v. b		55 – 0 kW	Done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
vi.	30 – 0 kW	30 – 0 kW	

Table 9 Test Point Summary – Step Loads with Surge Module/Variable Speed

For each step load point, an oscilloscope trace was captured that measured the power output, frequency, current, and voltage. These measurements were taken on the microgrid side (Y side) of the transformer. In each plot the data is formatted in the following way:

Ch1 = Unit RMS Power Output;

0.0V = -15KW

0.5V = 0KW

1.5V = 30KW

2.5V = 60KW

Ch2 = Unit Operating Frequency;
60Hz --> 2.3V
59.5Hz --> 1.66V
60.5Hz --> 2.94V

Ch 3 –Grid Voltage L-N

Channel 4

Ch4 = Unit Output Current; 1 V = 100Amps

Also, the Step “Up” load points (i-iv.) were run two separate times so that additional data on the system dynamics, with the surge module, could be captured. This oscilloscope data is formatted as follows:

Channel 1 = Engine RPM;
Not Recorded

Channel 2 = Bus Voltage
Zero point is actually 500 volts and measures from black “1” marker on left-hand side of Figure
100 volts per division
Nominal Voltage; 860 volts

Channel 3 = AC Current ; 1 V = 100 amps

Channel 4 = Surge Module Current
10 mV = 10 amps (*Need to verify with J. Wen of Youtility*)
10 mV per division
Nominal Current; 26 amps

The results of each test is organized in a table that defines the load setpoint (abbreviated S.P) and the actual power output from the unit. The table also contains the microgrid operating frequency before and after the transient event occurs (These frequency values are obtained from the units software and not the oscilloscope measurement). Also recorded in the table is the engine speed before and after the transient. Data contained in column A defines the operating condition and the state of the microgrid before the transient condition being tested occurs. Data contained in column B defines the operating condition and the state of the microgrid after the transient condition being tested has occurred.

i. Step Load Evaluation 1

4.Load Bank Start Load = 0 kW

5.Unit A CMD = 20 kW

6.Load Bank End Load = 30 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/30.5 kW
Frequency Hz	60.16 Hz	59.91 Hz
Engine Speed (Hz/rpm)	60 / 1800	60 / 1800

Table 10 Step Load Evaluation 1: 0 – 30 kW (w/Surge Module)

i. 0 – 30 KW Step Load –Surge Module- Variable Speed

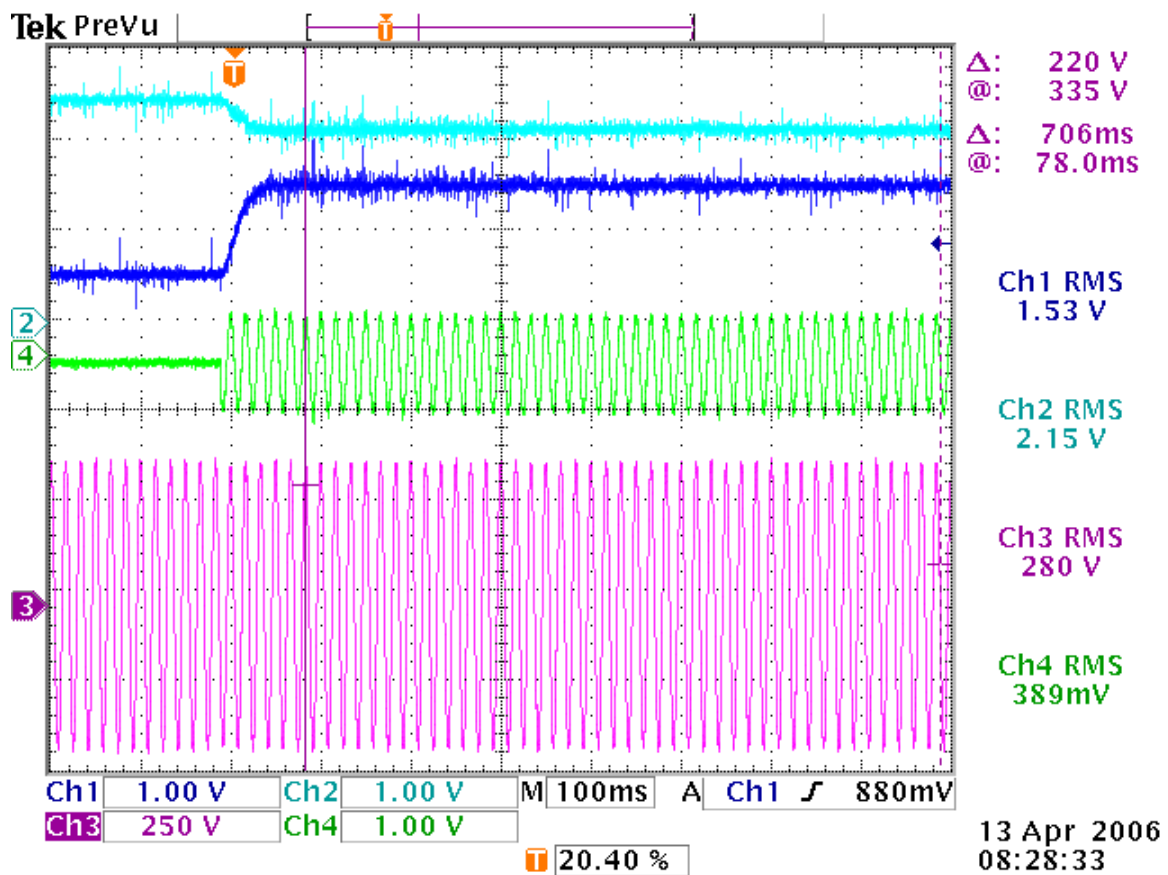


Figure 19 0 –30 kW: Power, Frequency, Voltage, Current

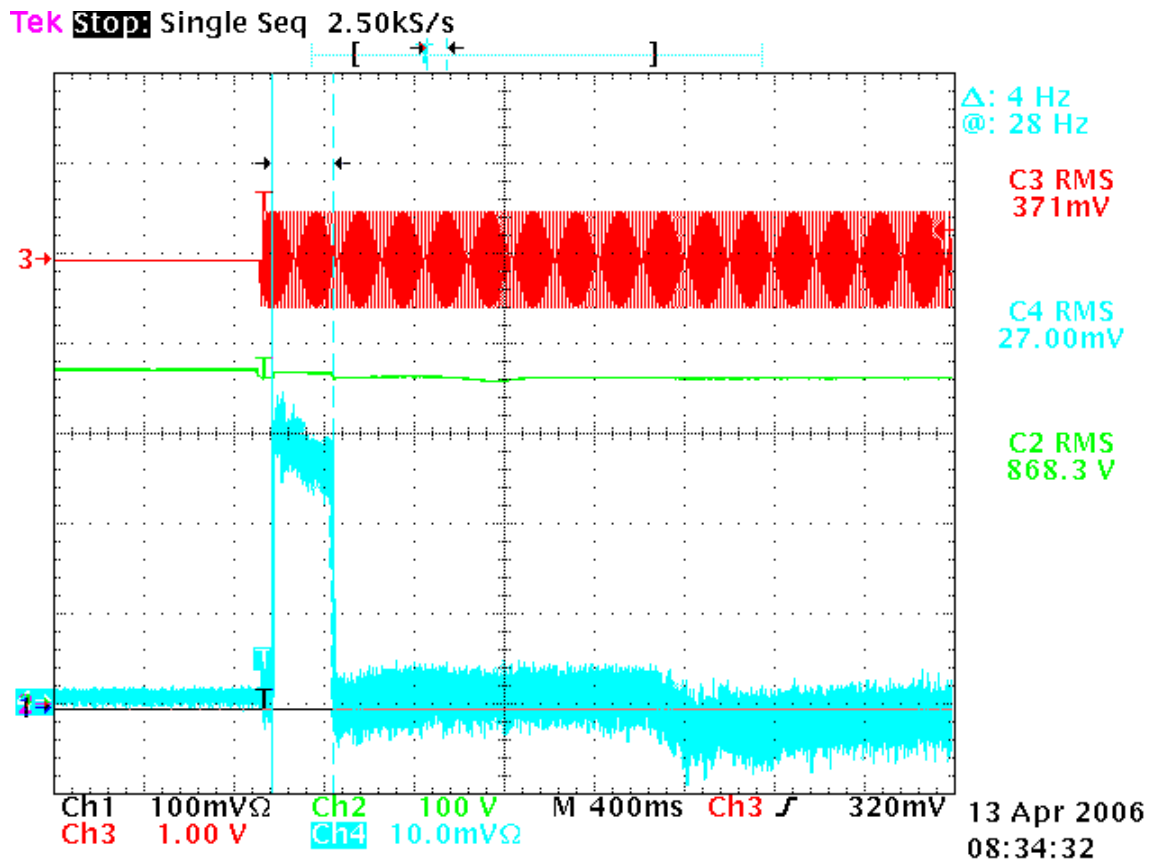


Figure 20 0 – 30 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

vi. Step Load Evaluation 2

7. Load Bank Start Load = 0KW
8. Unit A CMD = 20KW
9. Load Bank End Load =60 kW

ii a. 0 – 50 kW (Additional test point done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/50.9 kW
Frequency Hz	60.16 Hz	59.74 Hz
Engine Speed (Hz/rpm)	60/ 1800	67.7 / 2031

Table 11 Step Load Evaluation 2a: 0 – 50 kW (w/Surge Module)

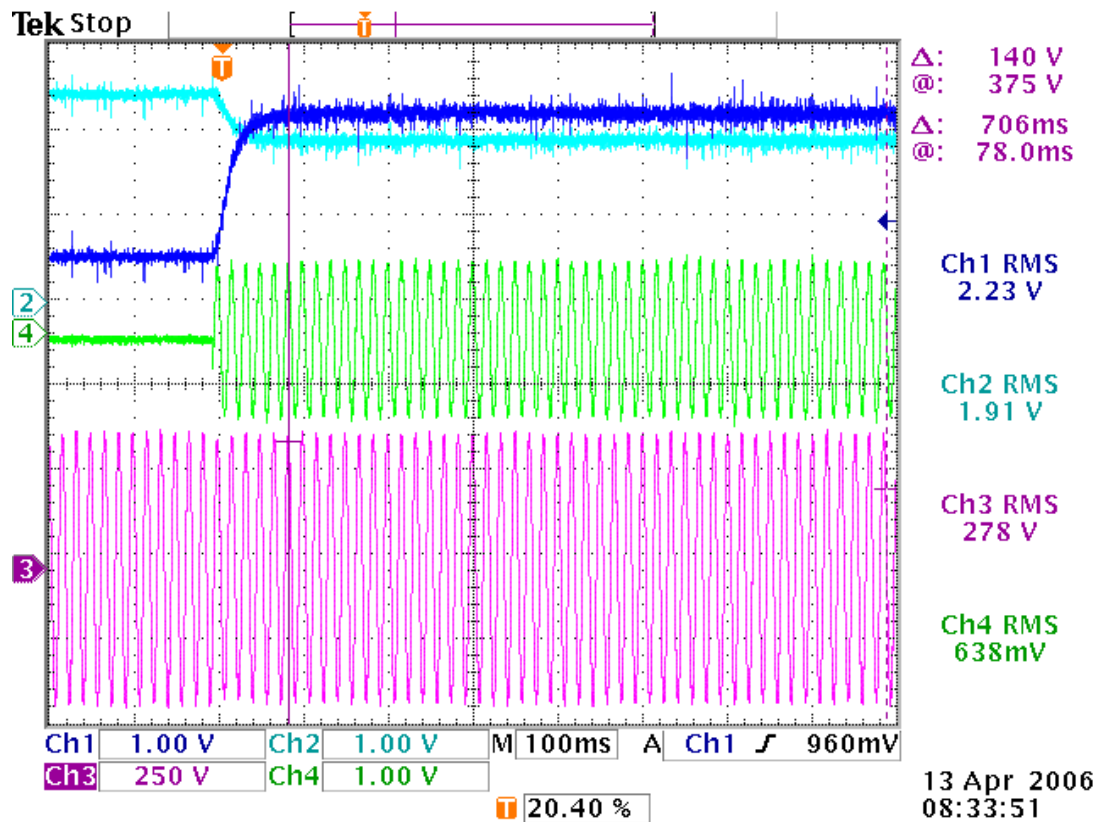


Figure 21 0–50 kW: Power, Frequency, Voltage, Current

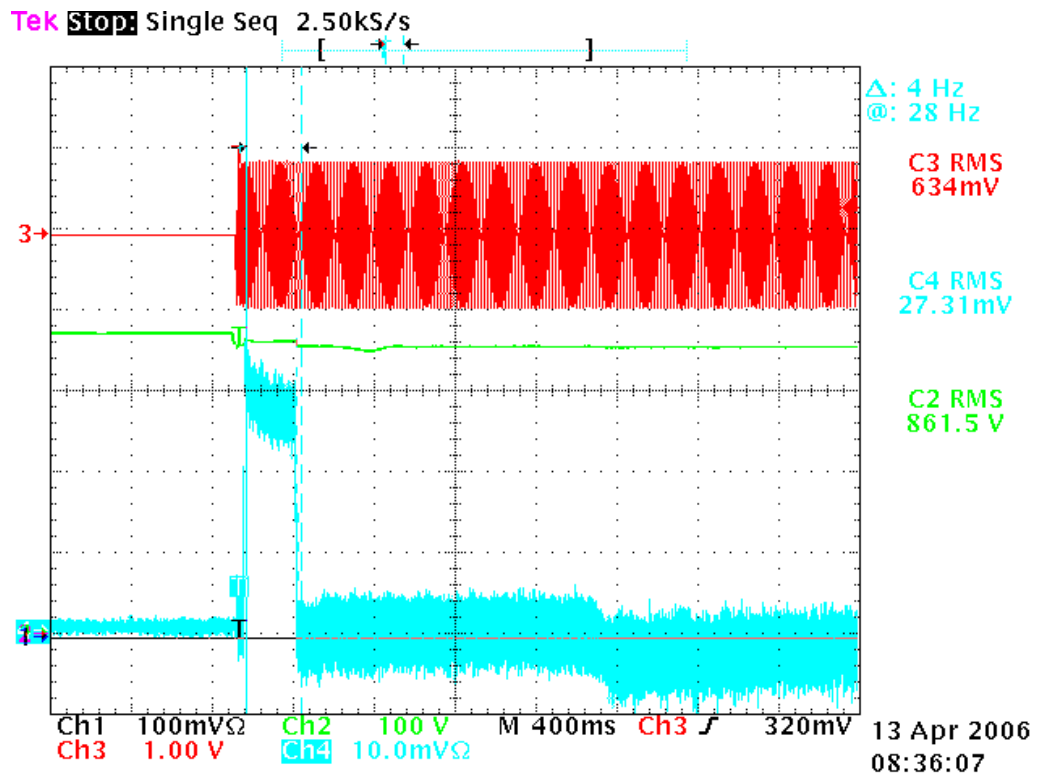


Figure 22 0–50 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

ii b. 0 – 60 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/60.7 kW
Frequency Hz	60.16 Hz	59.18 Hz
Engine Speed (Hz/rpm)	60 / 1800	72.7 / 2181

Table 12 Step Load Evaluation 2b: 0 – 60 kW (w/Surge Module)

ii b. 0 – 60 KW Step Load –Surge Module- Variable Speed

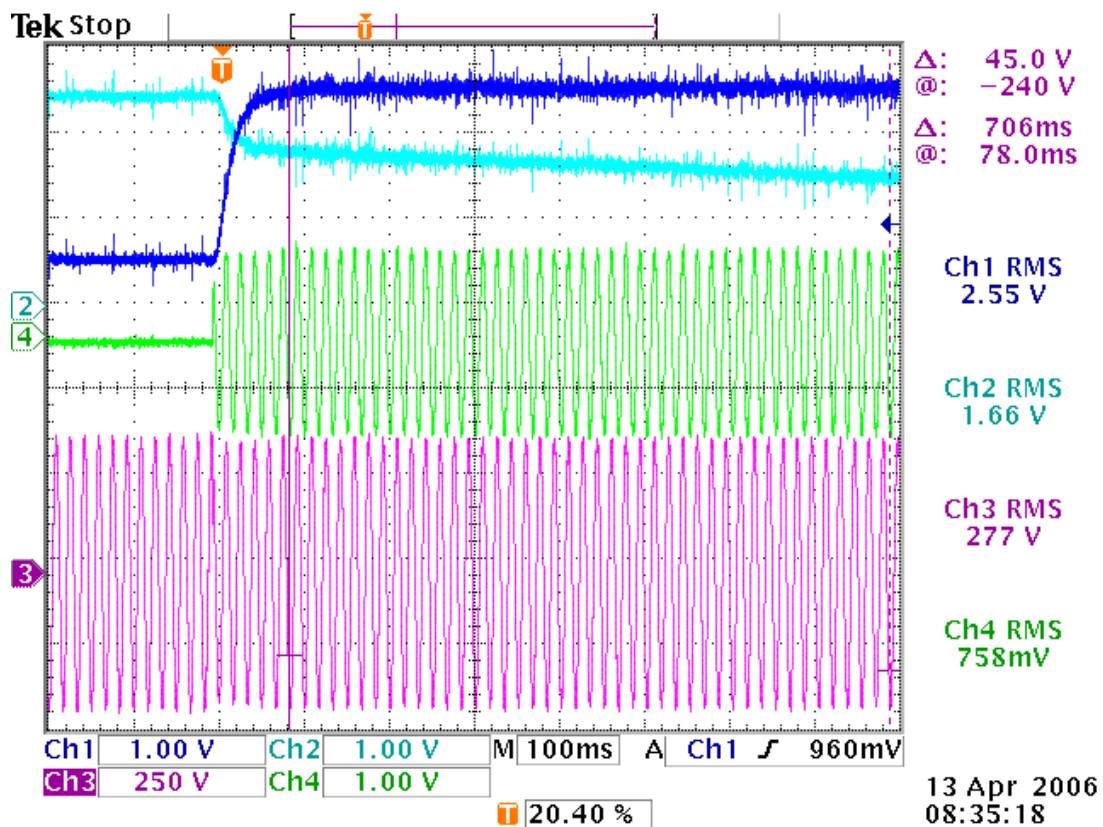


Figure 23 0 –60 kW: Power, Frequency, Voltage, Current

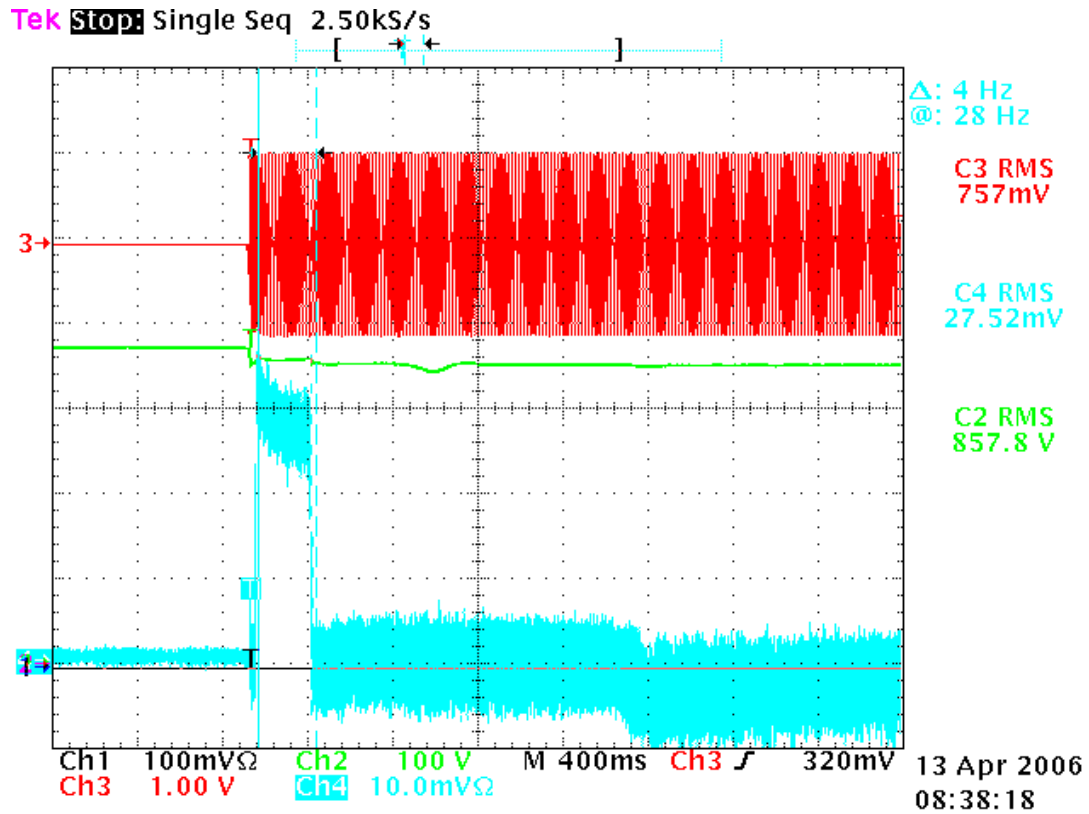


Figure 24 0 – 60 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

vii. Step Load Evaluation 3

- 1.Load Bank Start Load = 15 kW
- 2.Unit A CMD = 20 kW
- 3.Load Bank End Load =50 kW (Changed from 45 kW because easier to implement on Load Bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/15.5 kW	20.0/50.9 kW
Frequency Hz	60.03 Hz	59.74 Hz
Engine Speed (Hz/rpm)	60 / 1800	67.7/ 2031

Table 13 Step Load Evaluation 3: 15 – 50 kW (w/Surge Module)

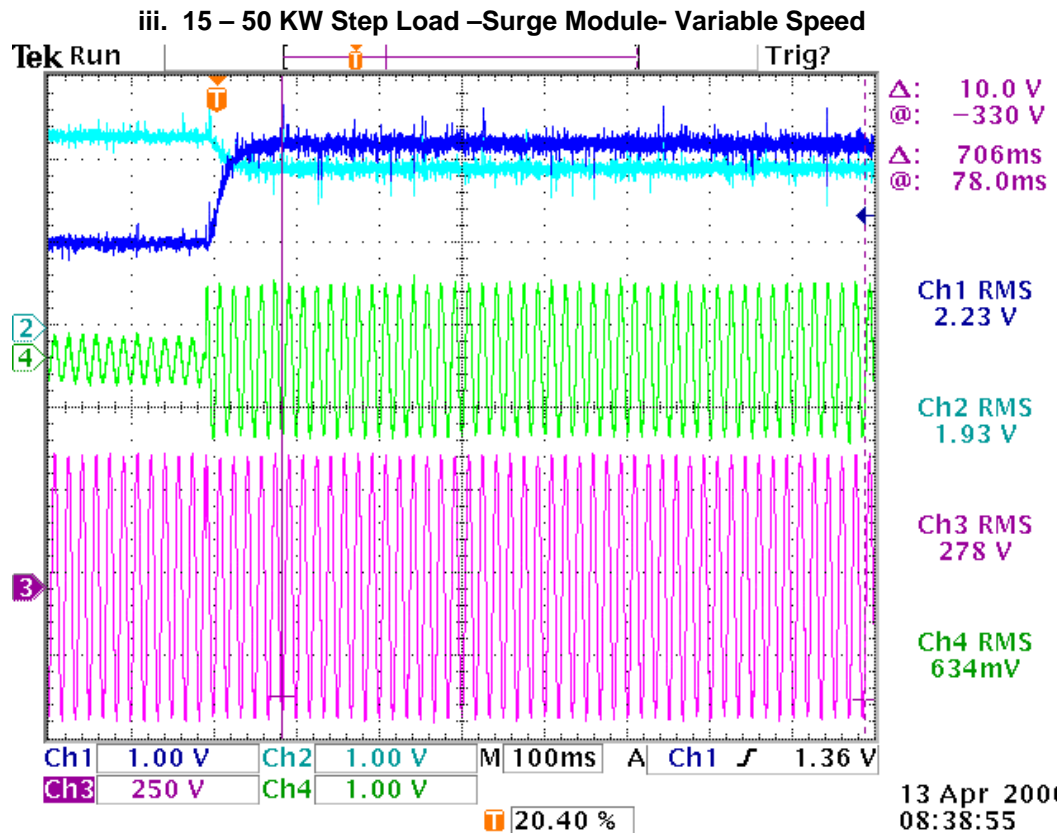


Figure 25 15 – 50 kW: Power, Frequency, Voltage, Current

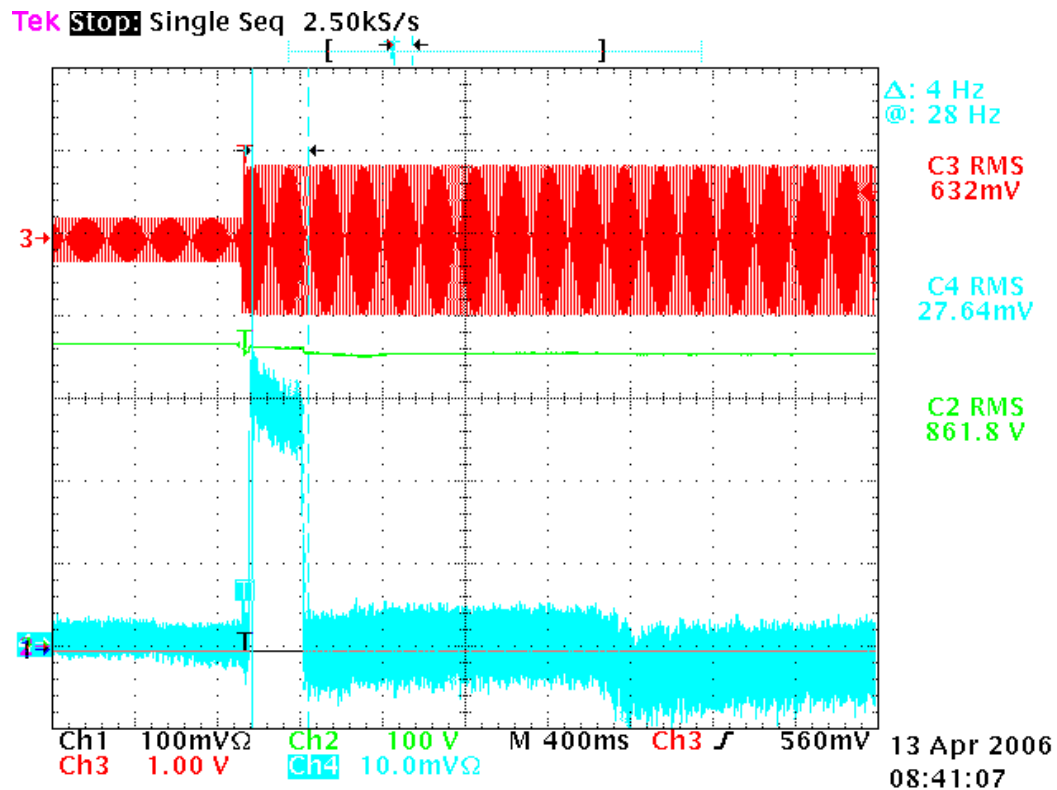


Figure 26 15 – 50 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

viii. Step Load Evaluation 4

- 1.Load Bank Start Load = 30 kW
- 2.Unit A CMD = 20 kW
- 3.Load Bank End Load = 60 kW

iv a. 30 – 55 kW (Additional test point done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank)

	A	B
Unit #1 (S.P/Actual) KW	20.0/30.4 kW	20.0/55.8 kW
Frequency Hz	59.91 Hz	59.70 Hz
Engine Speed (Hz/rpm)	60 / 1800	70.1/ 2103

Table 14 Step Load Evaluation 4a: 30 - 55 kW (w/Surge Module)

iv.a 30– 55 KW Step Load –Surge Module- Variable Speed

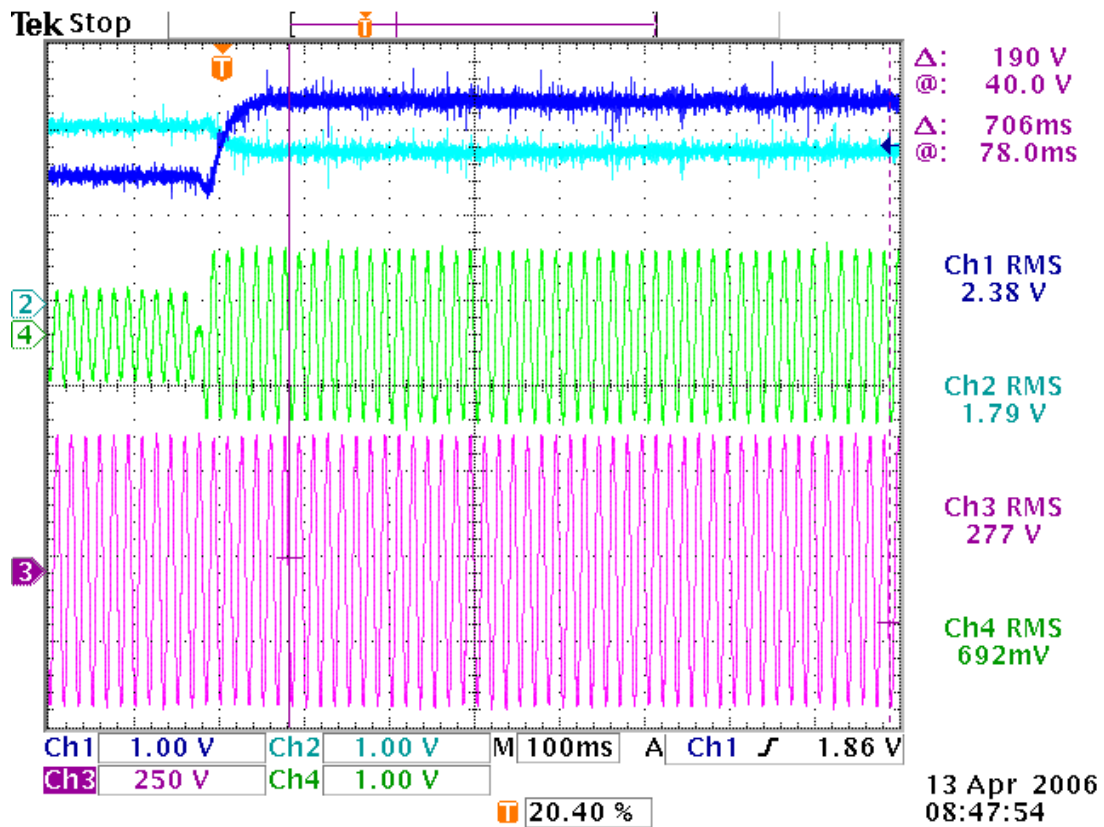


Figure 27 30 –55 kW: Power, Frequency, Voltage, Current

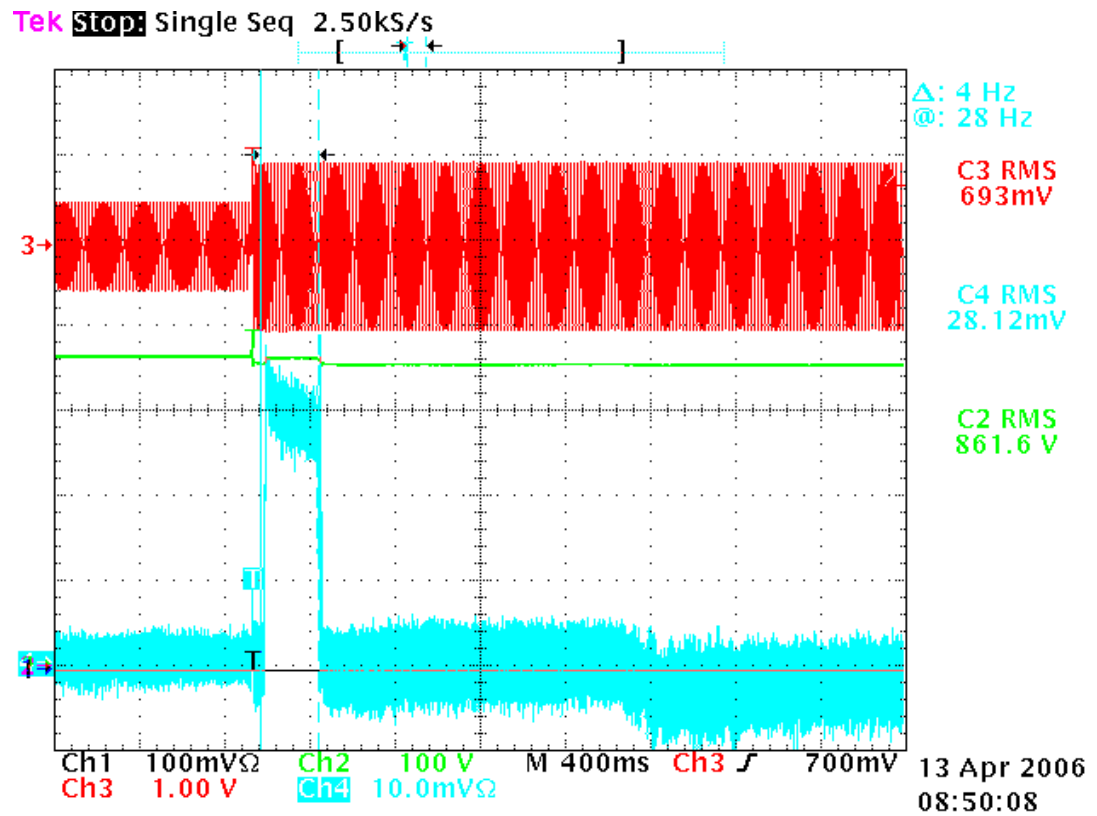


Figure 28 30 – 55 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

iv b. 30 – 60 kW

	A	B
Unit #1 (S.P/Actual) KW	20.0/30.4 kW	20.0/60.7 kW
Frequency Hz	59.91 Hz	59.16 Hz
Engine Speed (Hz/rpm)	60 / 1800	72.5/ 2175

Table 15 Step Load Evaluation 4b: 30 – 60 kW (w/Surge Module)

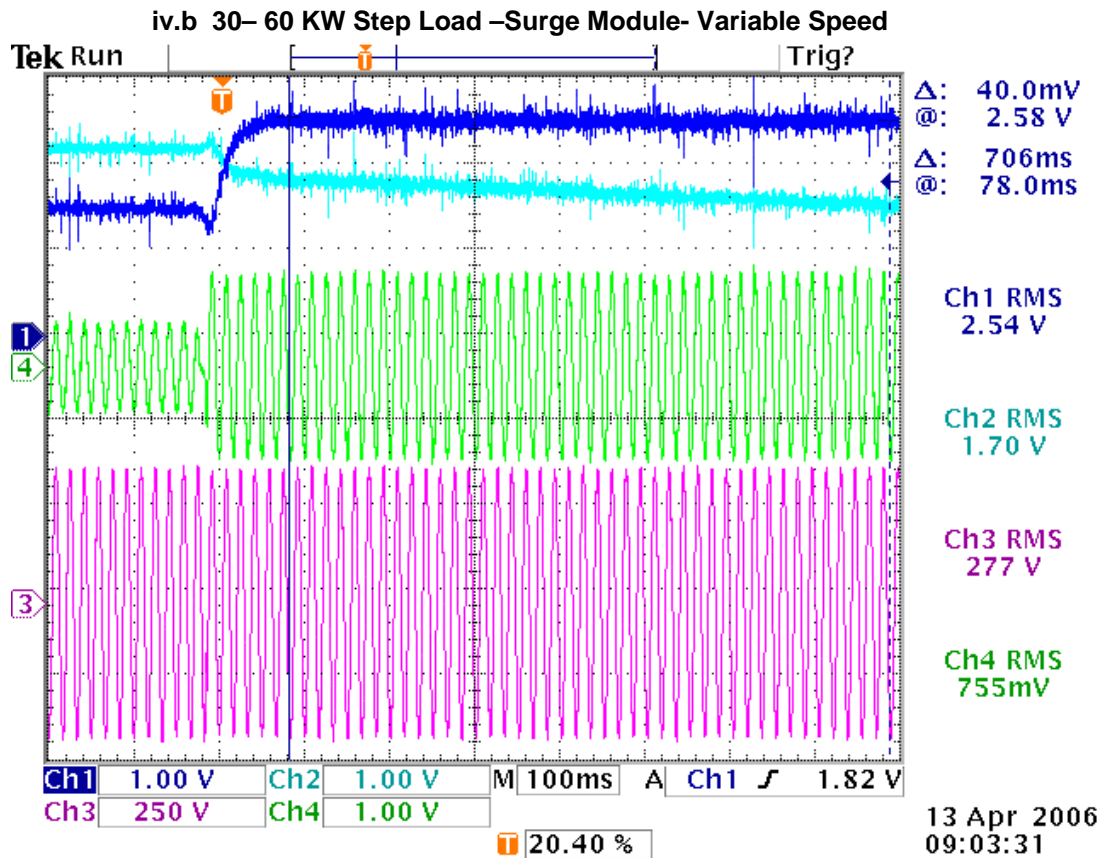


Figure 29 30 –60 kW: Power, Frequency, Voltage, Current

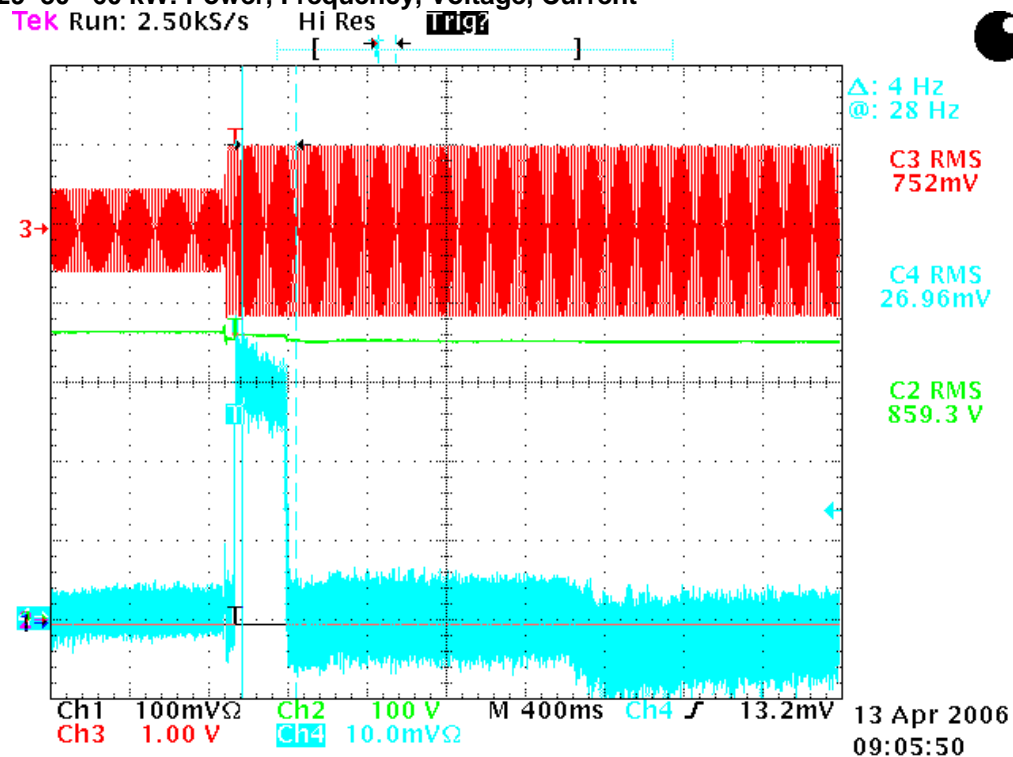


Figure 30 30 – 60 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

ix. Step Load Evaluation 5

1. Load Bank Start Load = 60 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 0 kW

v a. 60 - 0 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/60.7 kW	20.0/0 kW
Frequency Hz	59.16 Hz	60.16 Hz
Engine Speed (Hz/rpm)	72.5/ 2175	60/1800

Table 16 Step Load Evaluation 5a: 60 - 0 kW (w/Surge Module)

60- 0 kW Step Load –Surge Module- Variable Speed

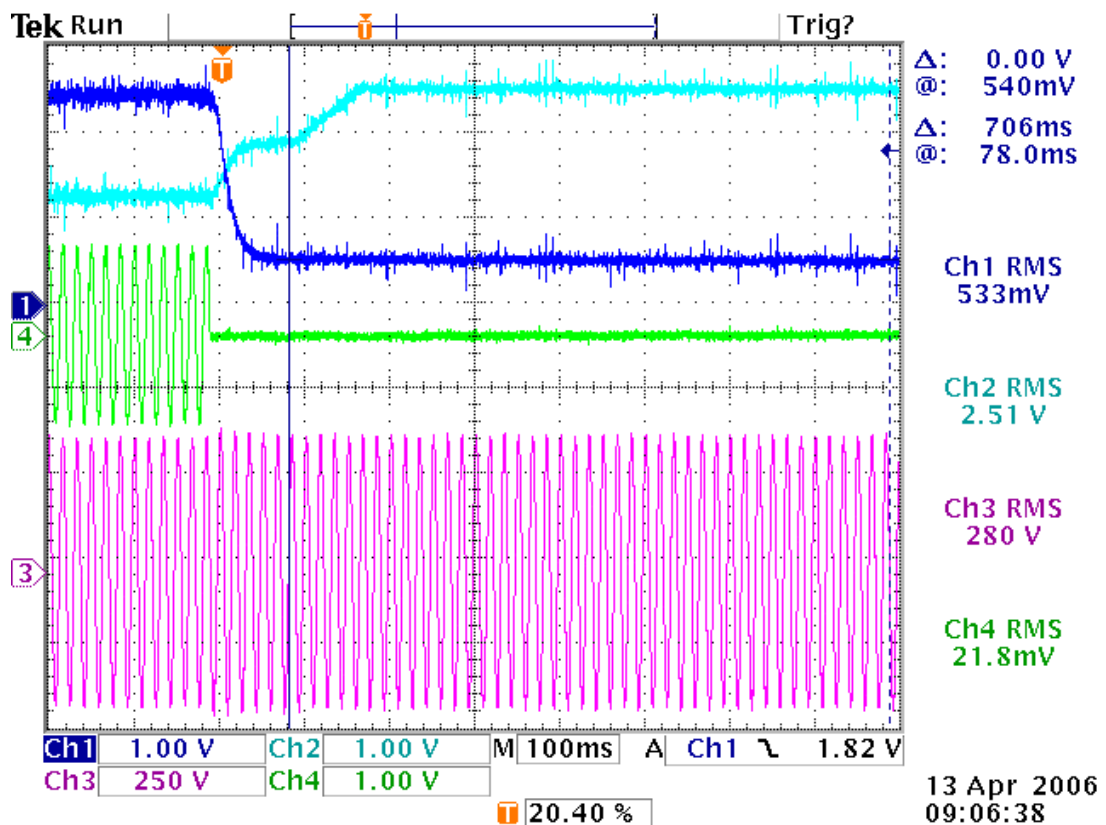


Figure 31 60 - 0 kW: Power, Frequency, Voltage, Current

v b. 55 - 0 kW (Additional test point done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/55.8 kW	20.0/0 kW
Frequency Hz	59.70 Hz	60.16 Hz
Engine Speed (Hz/rpm)	70.1/ 2103	60/1800

Table 17 Step Load Evaluation 5b: 55 - 0 kW (w/Surge Module)

55- 0 kW Step Load –Surge Module- Variable Speed

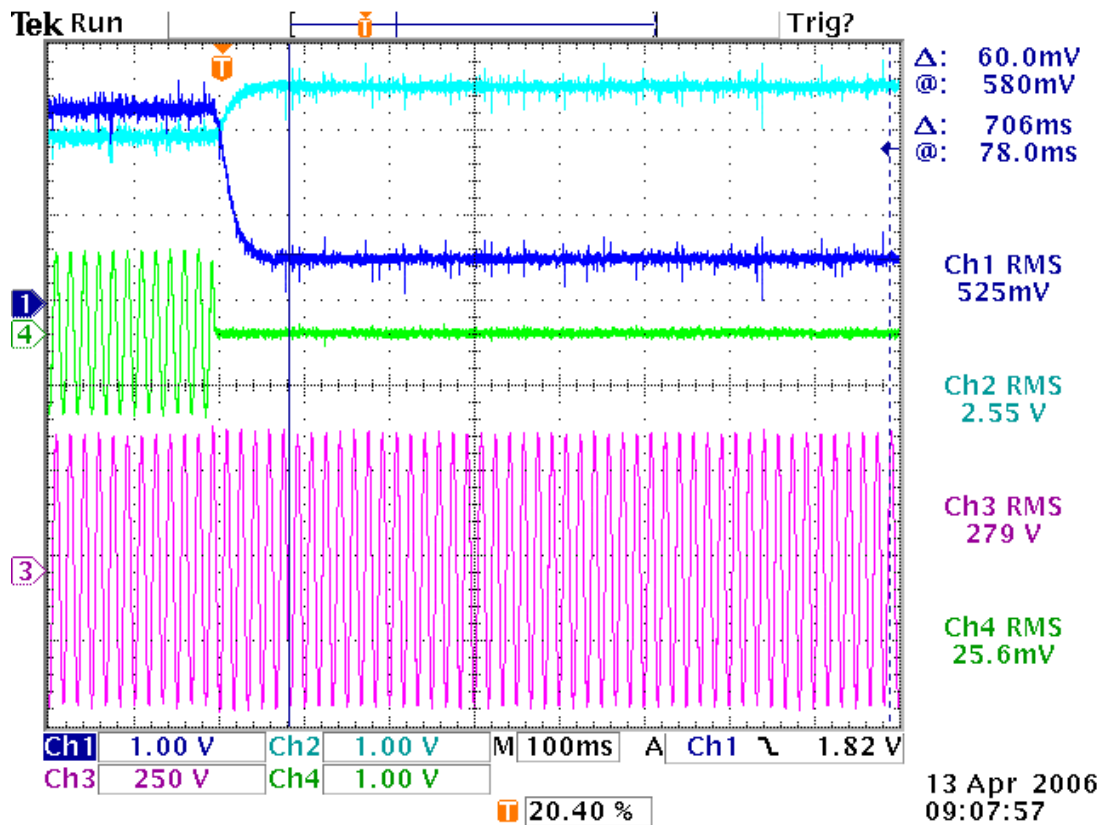


Figure 32 55 – 0 kW: Power, Frequency, Voltage, Current

vi. Step Load Evaluation 6

4. Load Bank Start Load = 30 kW
5. Unit A CMD = 20 kW
6. Load Bank End Load = 0 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/30.4 kW Unit	20.0/0 kW
Frequency Hz	59.91 Hz	60.16 Hz
Engine Speed (Hz/rpm)	60/ 1800	60/1800

Table 18 Step Load Evaluation 6: 30 – 0 kW (w/Surge Module)

30– 0 kW Step Load –Surge Module- Variable Speed

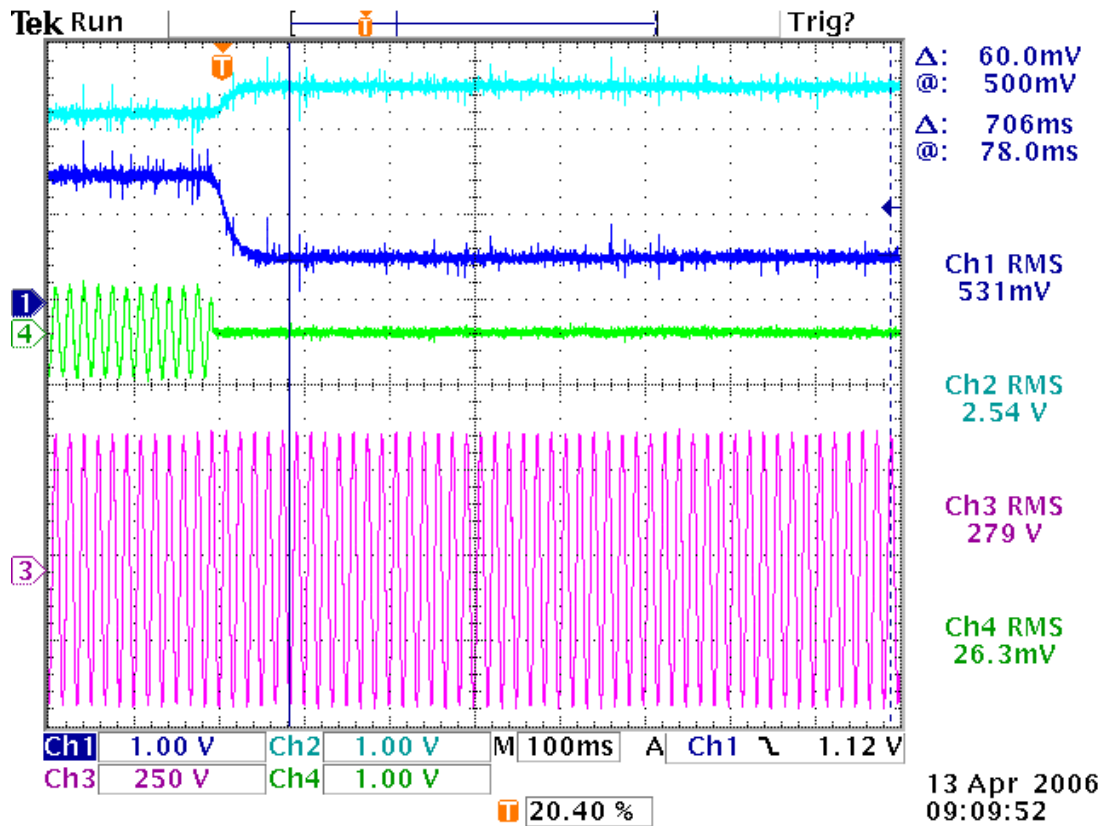


Figure 33 30 – 0 kW: Power, Frequency, Voltage, Current

B.3. Step Load Evaluations without Surge Module – Fixed Speed Operation

The CHP unit was tested with the surge module disabled. As with the first unit (Serial # 200835), the results confirmed that the dynamics of the engine/inverter allows the unit to successfully handle a step load without the surge module. The engine was set at the fixed speed required for the maximum load step of 0 – 60 kW (2160 rpm). Each step load point was run to confirm Pass/Fail. Oscilloscope data was not recorded since, as demonstrated in the testing of Unit #200835, if the unit “Passes”, the electrical output signatures (Figure 1) are the same as in Variable Speed operation.

The following table summarizes the test results.

Fixed Engine Speed 2160 rpm (72 Hz) No Surge Module		
	Step Load	Pass/Fail
i.	0 – 30 kW	Pass
ii. a	0 – 50 kW	Pass
ii. b	0 – 60 kW	Pass
iii.	15 – 50 kW	Pass
iv. a	30 – 55 kW	Pass
iv. b	30 – 60 kW	Pass
v. a	60 – 0 kW	Pass
v. b	55 – 0 kW	Pass
vi.	30 – 0 kW	Pass

Table 19 Test Point Summary – Step Loads without Surge Module/Fixed Speed

**TECOGEN 60 kW
Inverter-Based CHP Modules**

CERTS Microgrid Test Bed Project

**Tecogen Factory Testing
Unit Serial #200837**

5/09/06

Introduction

This report presents the factory test data of the third Tecogen CHP unit (Serial # 200837), equipped with a customized inverter (by Youtility) that is configured with the CERTS microgrid control algorithm. Figure 1 presents a one-line diagram of the test set-up. The unit generates power in a stand-alone mode (no grid-tie) and is connected to a load bank. The output of the inverter is connected to the Delta side of a transformer in a 3-wire configuration. The output of the transformer is wired to the load bank in a 4-wire configuration with a 25-yard loop.

The inverter is also equipped with a Surge Module wired directly to the DC Bus. The Surge Module is a battery powered energy storage device with a rating of 20 kW for 3 seconds. Its purpose is to assist the engine/inverter's response to step loads. It is housed separately in an adjacent cabinet (DC power wiring length: 12.5 feet).

All testing was done with the inverters set to Power Control Mode.

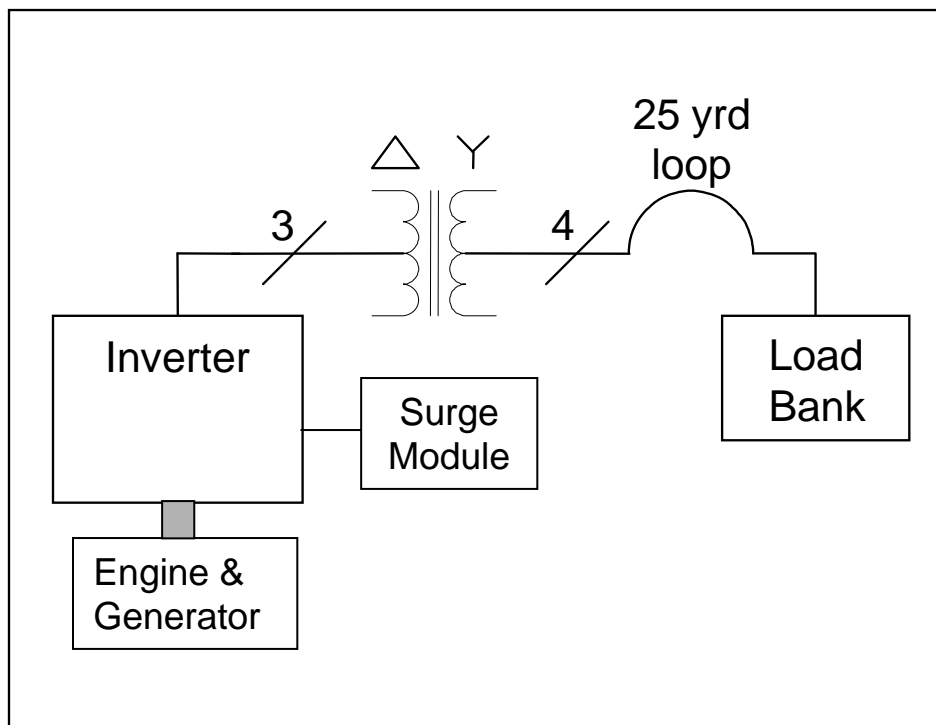


Figure 34 Factory Test One-line Diagram

B.2. Step Load Evaluations with Surge Module – Variable Speed Operation

All data was taken with the following settings in the software:

Minimum Engine Speed: 60 Hz (1800 rpm)

Maximum Engine Speed: 72 Hz (2160 rpm)

The following step loads were tested :

	Test Plan	Actual Test Point	Comments
i.	0-30 kW	0 – 30 kW	
ii. a		0 – 50 kW	Done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
ii. b	0 – 60 kW	0 – 60 kW	
iii.	15 – 45 kW	15 – 50 kW	Changed to 50 kW because easier to implement on load bank
iv. a		30 – 55 kW	Done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
iv. b	30 – 60 kW	30 – 60 kW	
v. a	60 – 0 kW	60 – 0 kW	
v. b		55 – 0 kW	Done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank.
vi.	30 – 0 kW	30 – 0 kW	

Table 20 Test Point Summary – Step Loads with Surge Module/Variable Speed

For each step load point, an oscilloscope trace was captured that measured the power output, frequency, current, and voltage. These measurements were taken on the microgrid side (Y side) of the transformer. In each plot the data is formatted in the following way:

Ch1 = Unit RMS Power Output;

0.0V = -15KW

0.5V = 0KW

1.5V = 30KW

2.5V = 60KW

Ch2 = Unit Operating Frequency;

60Hz --> 2.3V

59.5Hz --> 1.66V

60.5Hz --> 2.94V

Ch 3 –Grid Voltage L-N

Channel 4

Ch4 = Unit Output Current; 1 V = 100Amps

Also, the Step “Up” load points (i-iv.) were run two separate times so that additional data on the system dynamics, with the surge module, could be captured. This oscilloscope data is formatted as follows:

Channel 1 = Engine RPM;

Not Recorded

Channel 2 = Bus Voltage

Zero point is actually 500 volts and measures from black “1” marker on left-hand side of figure

100 volts per division

Nominal Voltage; 860 volts

Channel 3 = AC Current ; 1 V = 100 amps

Channel 4 = Surge Module Current

10 mV = 10 amps

10 mV per division

Nominal Current; 26 amps

The results of each test is organized in a table that defines the load setpoint (abbreviated S.P) and the actual power output from the unit. The table also contains the microgrid operating frequency before and after the transient event occurs (These frequency values are obtained from the units software and not the oscilloscope measurement). Also recorded in the table is the engine speed before and after the transient. Data contained in column A defines the operating condition and the state of the microgrid before the transient condition being tested occurs. Data contained in column B defines the operating condition and the state of the microgrid after the transient condition being tested has occurred.

i. Step Load Evaluation 1

4. Load Bank Start Load = 0 kW

5. Unit A CMD = 20 kW

6. Load Bank End Load = 30 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/30.5 kW
Frequency Hz	60.16 Hz	59.91 Hz
Engine Speed (Hz/rpm)	60 / 1800	60 / 1800

Table 21 Step Load Evaluation 1: 0 – 30 kW (w/Surge Module)

i. 0 – 30 KW Step Load –Surge Module- Variable Speed

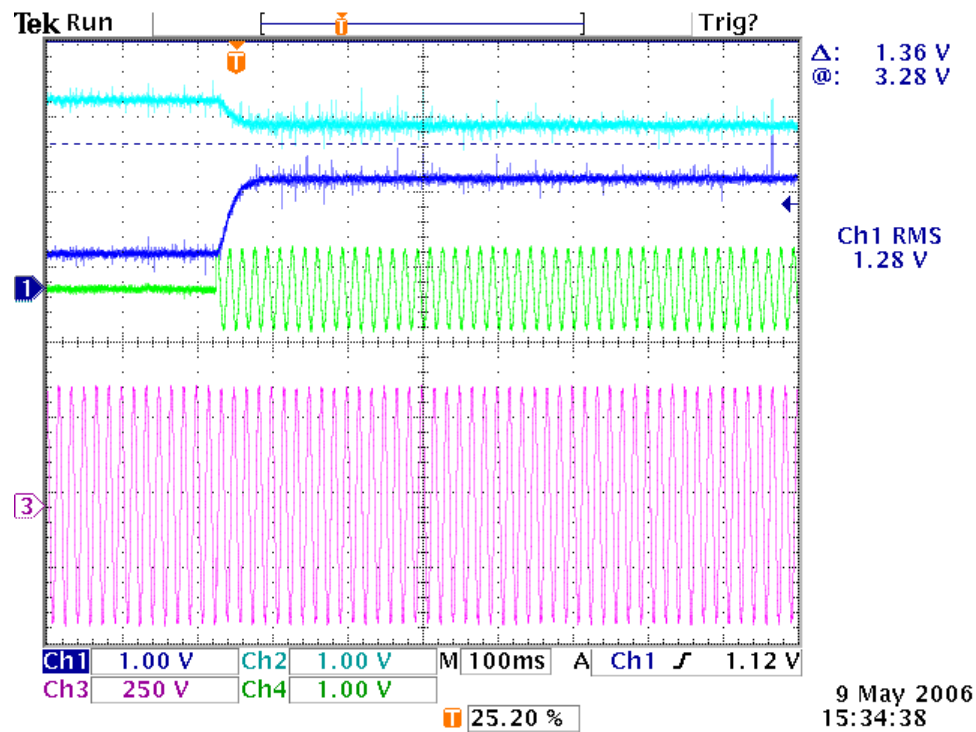


Figure 35 0 –30 kW: Power, Frequency, Voltage, Current

x. Step Load Evaluation 2

10. Load Bank Start Load = 0KW

11. Unit A CMD = 20KW

12. Load Bank End Load =60 kW

ii a. 0 – 50 kW (Additional test point done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/51.3 kW
Frequency Hz	60.16 Hz	59.73 Hz
Engine Speed (Hz/rpm)	60/ 1800	65.9 / 1977

Table 22 Step Load Evaluation 2a: 0 – 50 kW (w/Surge Module)

ii a. 0 – 50 kW Step Load –Surge Module- Variable Speed

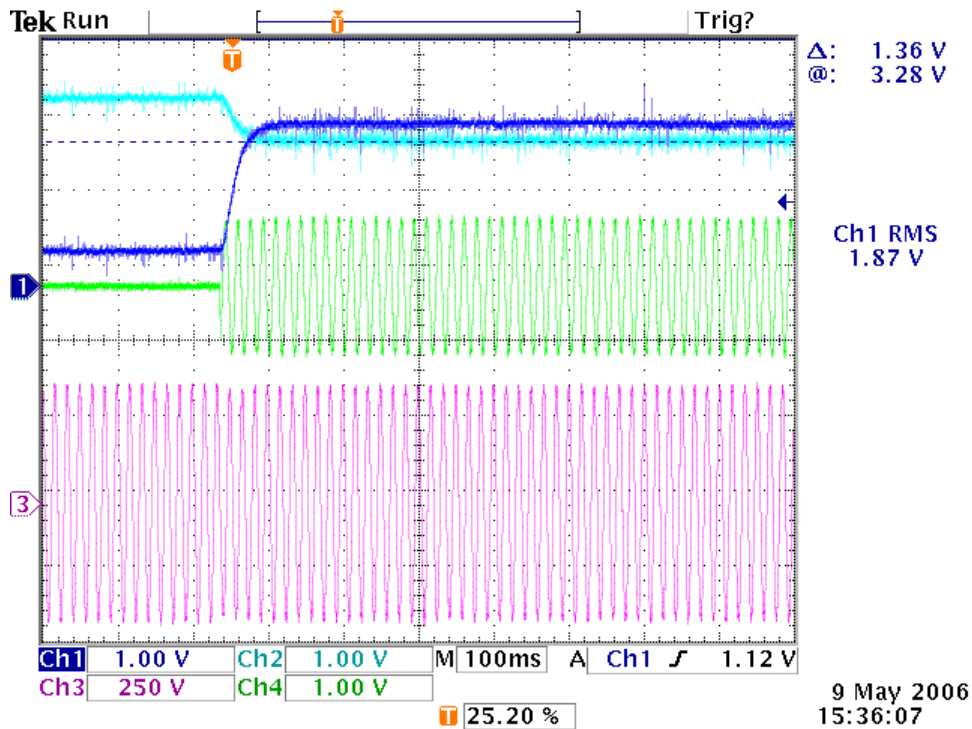


Figure 36 0 –50 kW: Power, Frequency, Voltage, Current

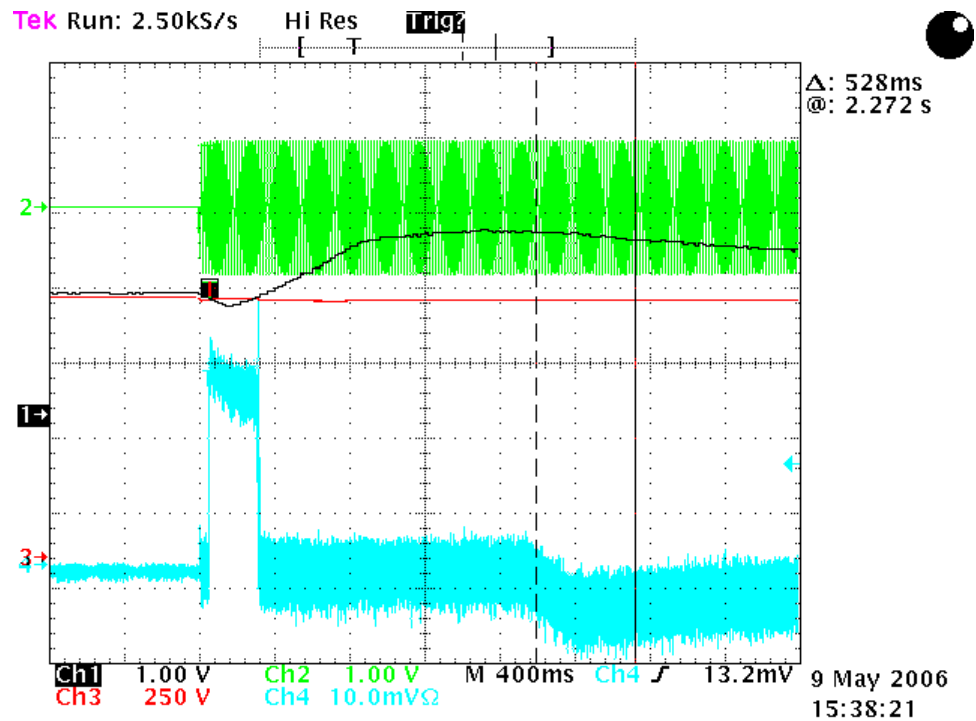


Figure 37 0 – 50 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

ii b. 0 – 60 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/0.0 kW	20.0/61.0 kW
Frequency Hz	60.16 Hz	59.16 Hz
Engine Speed (Hz/rpm)	60 / 1800	67.8 / 2034

Table 23 Step Load Evaluation 2b: 0 – 60 kW (w/Surge Module)

ii b. 0 – 60 kW Step Load –Surge Module- Variable Speed

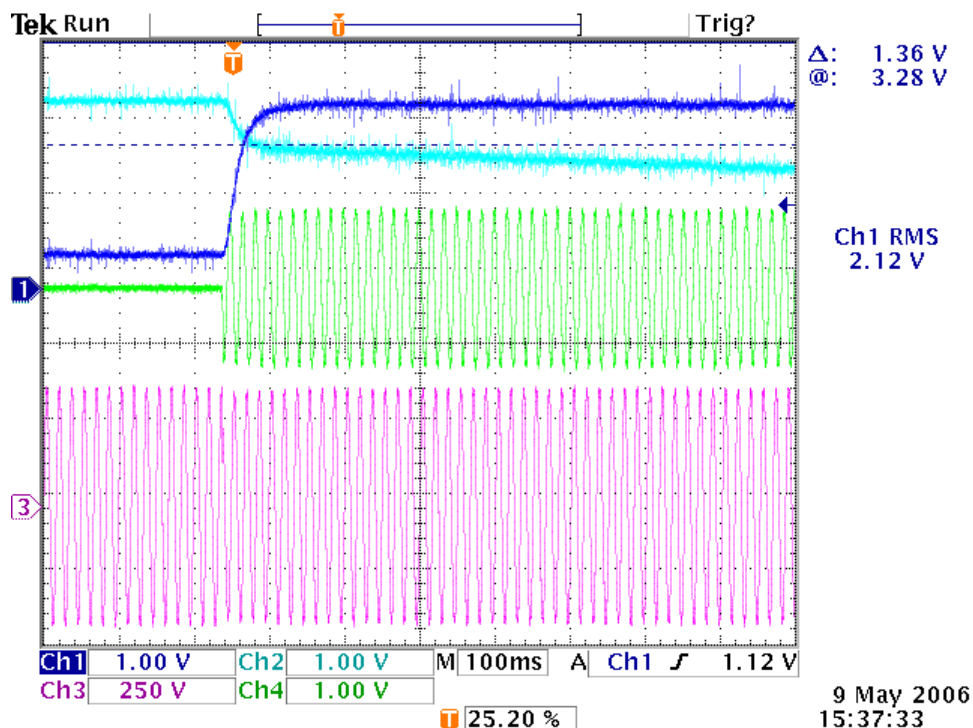


Figure 38 0 –60 kW: Power, Frequency, Voltage, Current

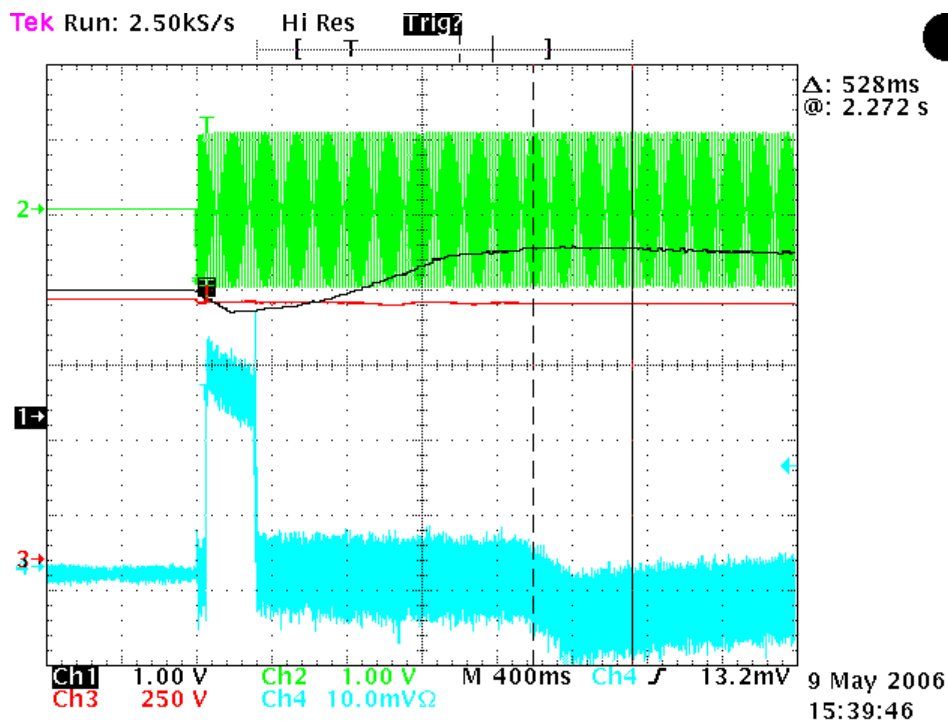


Figure 39 0 – 60 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

xi. Step Load Evaluation 3

1. Load Bank Start Load = 15 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 50 kW (Changed from 45 kW because easier to implement on Load Bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/15.5 kW	20.0/50.9 kW
Frequency Hz	60.03 Hz	59.74 Hz
Engine Speed (Hz/rpm)	60 / 1800	67.7 / 2031

Table 24 Step Load Evaluation 3: 15 - 50 kW (w/Surge Module)

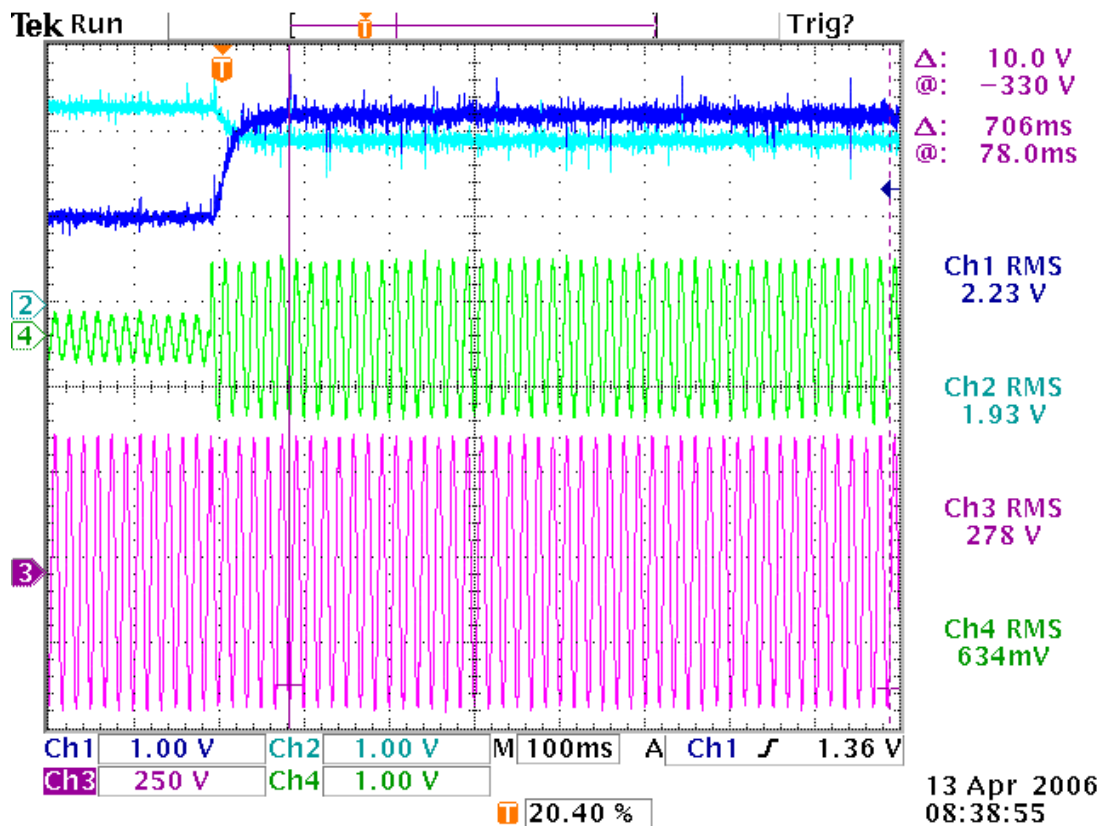


Figure 40 15 – 50 kW: Power, Frequency, Voltage, Current

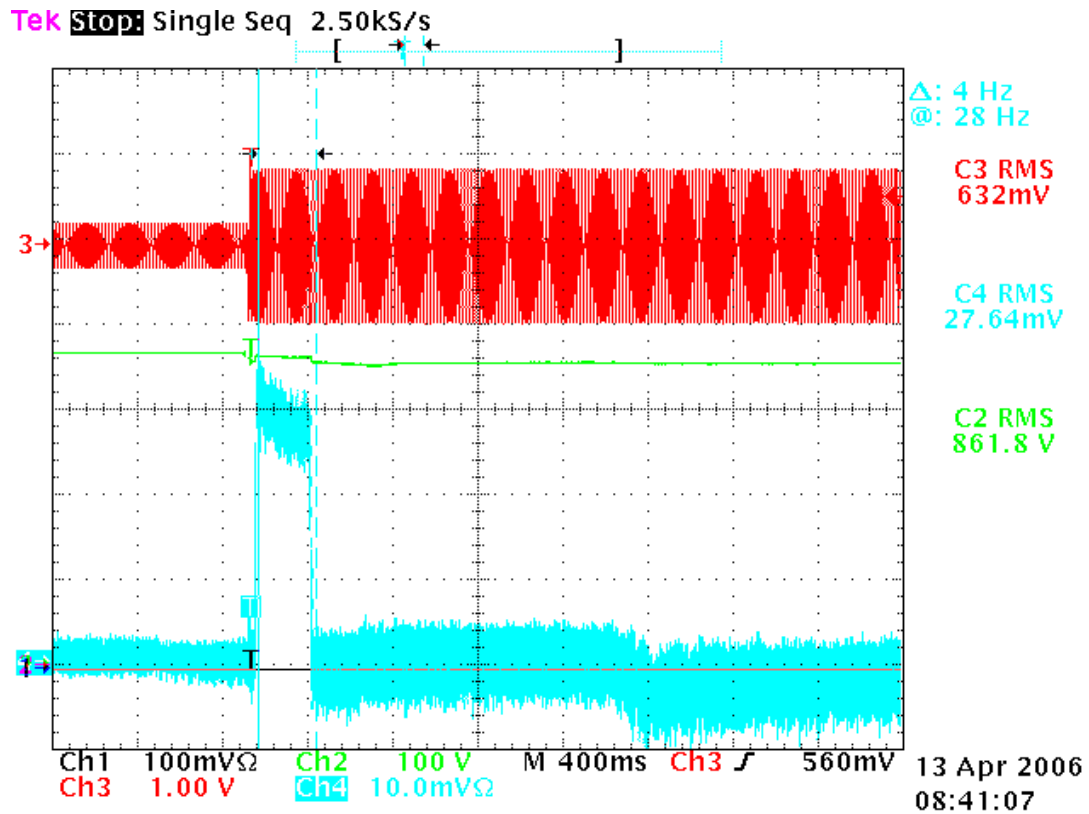


Figure 41 15 – 50 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

xii. Step Load Evaluation 4

1. Load Bank Start Load = 30 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 60 kW

iv a. 30 – 55 kW (Additional test point done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank)

	A	B
Unit #1 (S.P/Actual) KW	20.0/30.4 kW	20.0/55.8 kW
Frequency Hz	59.91 Hz	59.70 Hz
Engine Speed (Hz/rpm)	60 / 1800	70.1/ 2103

Table 25 Step Load Evaluation 4a: 30 – 55 kW (w/Surge Module)

iv.a 30– 55 KW Step Load –Surge Module- Variable Speed

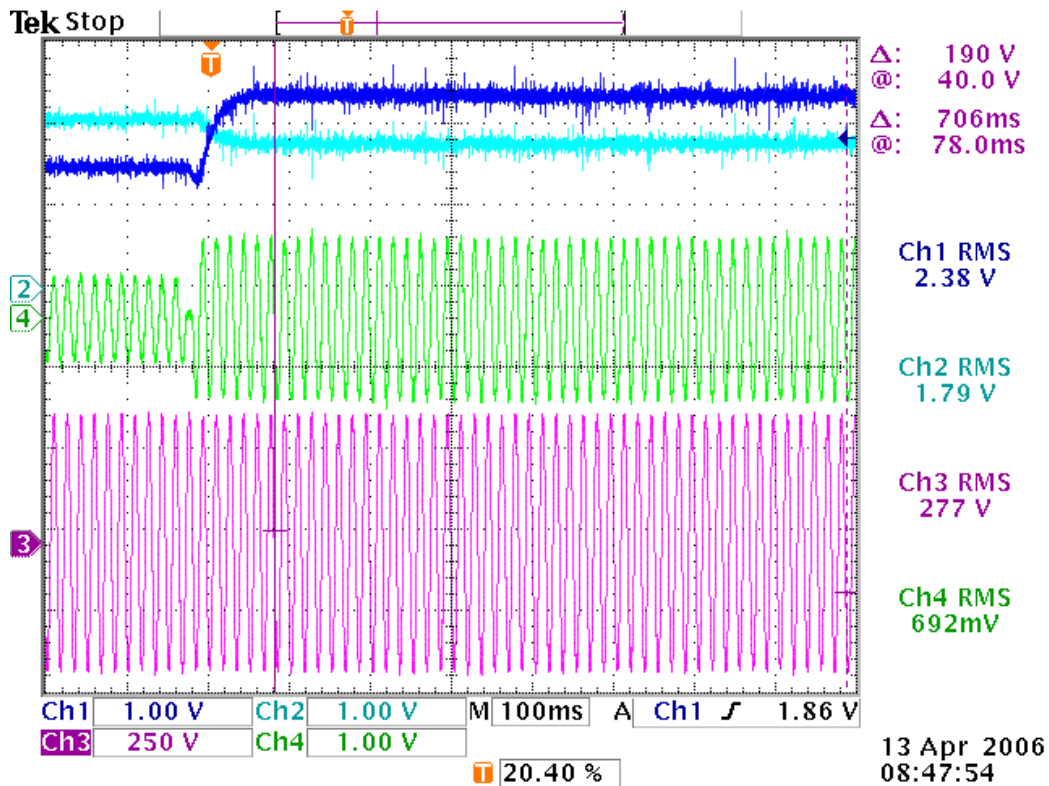


Figure 42 30 –55 kW: Power, Frequency, Voltage, Current

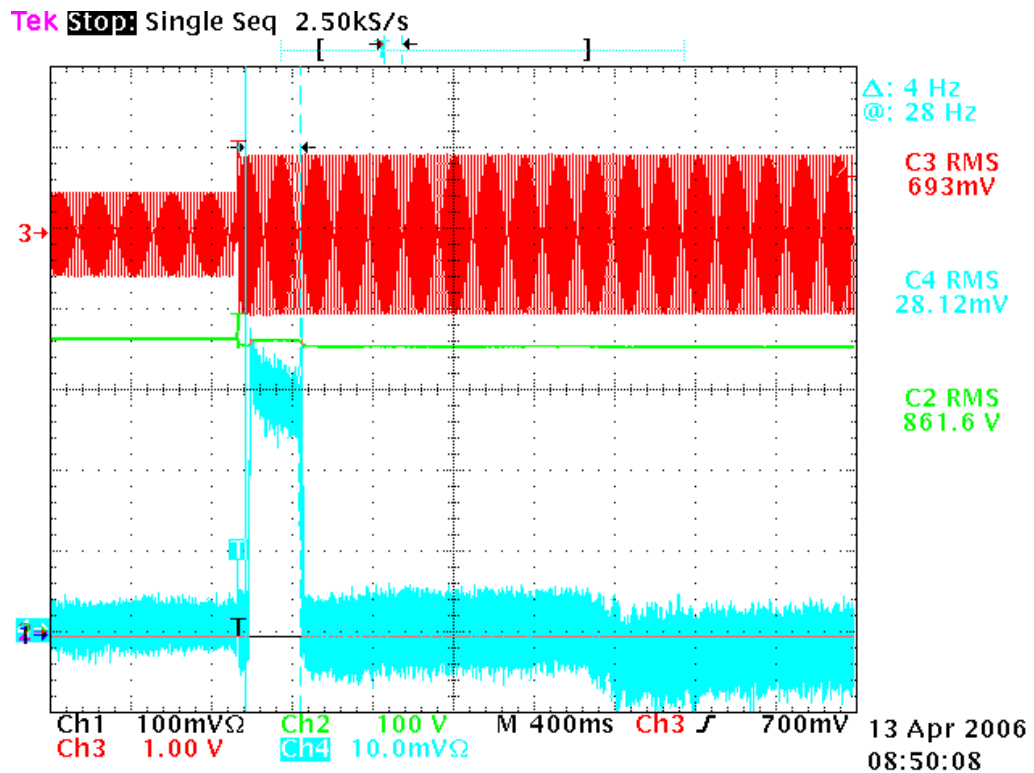


Figure 43 30 – 55 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

iv b. 30 – 60 kW

	A	B
Unit #1 (S.P/Actual) KW	20.0/30.4 kW	20.0/60.7 kW
Frequency Hz	59.91 Hz	59.16 Hz
Engine Speed (Hz/rpm)	60 / 1800	72.5/ 2175

Table 26 Step Load Evaluation 4b: 30 – 60 kW (w/Surge Module)

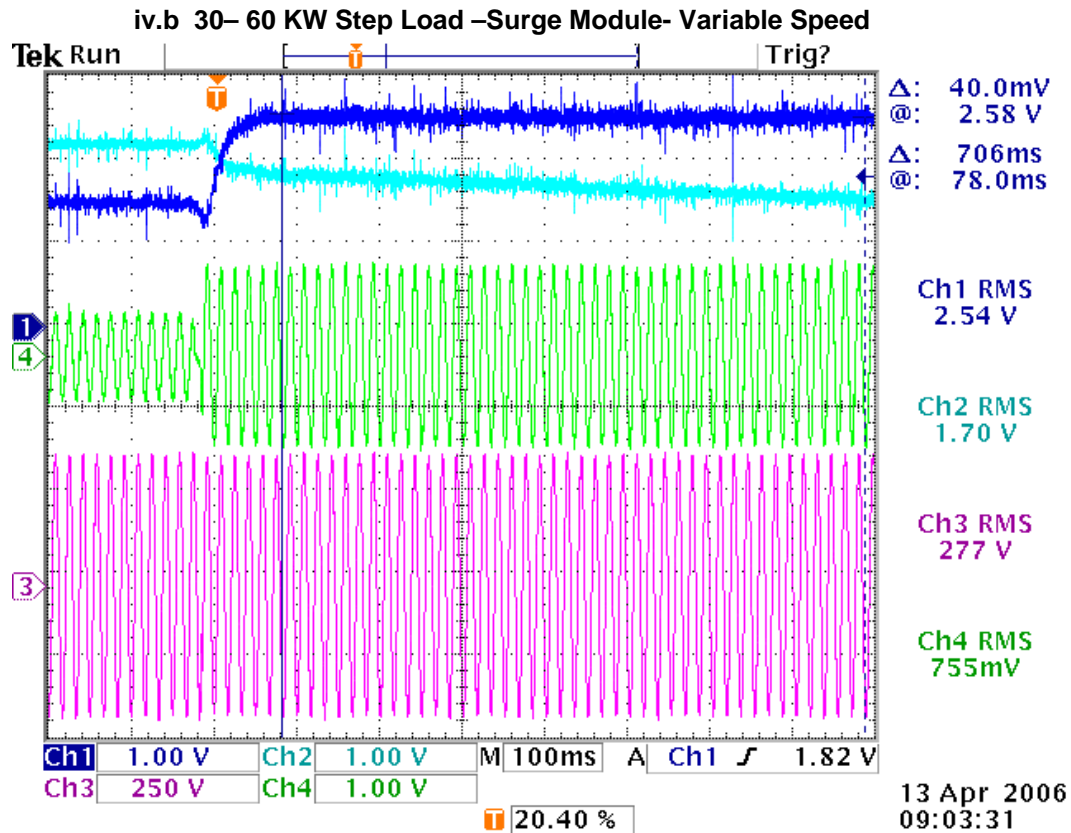


Figure 44 30 – 60 kW: Power, Frequency, Voltage, Current

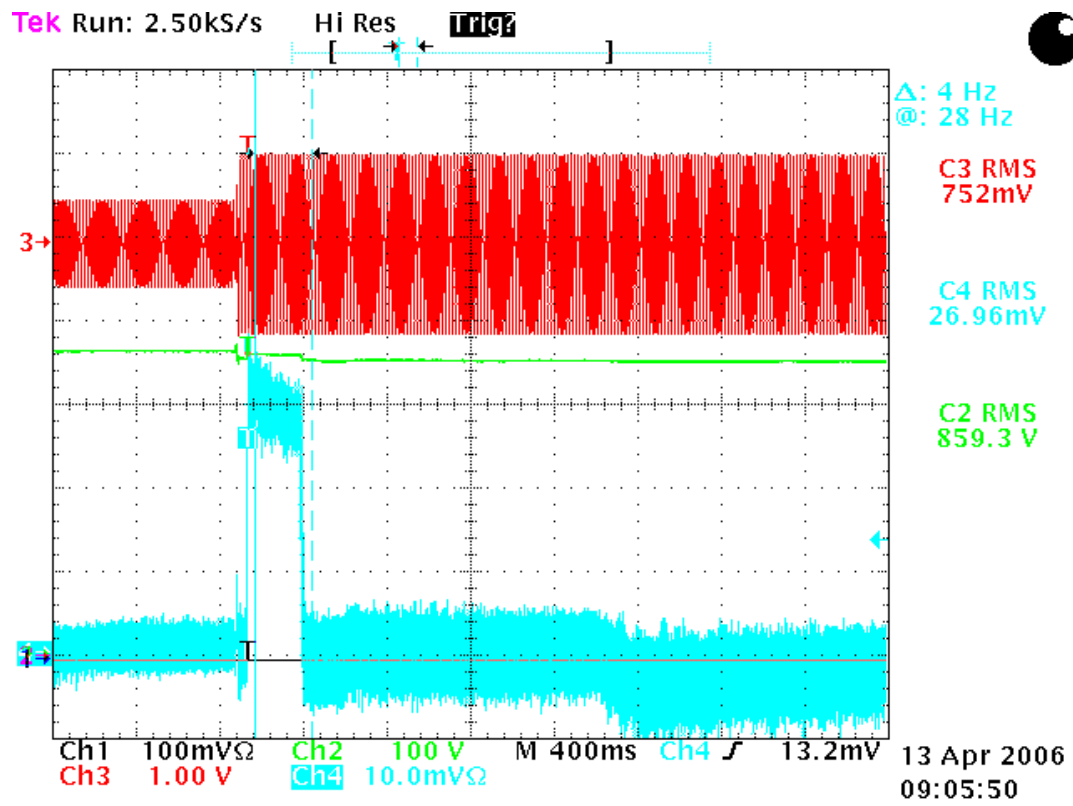


Figure 45 30 – 60 kW: Engine RPM, Bus Voltage, AC Current, Surge Module Current

xiii. Step Load Evaluation 5

1. Load Bank Start Load = 60 kW
2. Unit A CMD = 20 kW
3. Load Bank End Load = 0 kW

v a. 60 - 0 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/60.7 kW	20.0/0 kW
Frequency Hz	59.16 Hz	60.16 Hz
Engine Speed (Hz/rpm)	72.5/ 2175	60/1800

Table 27 Step Load Evaluation 5a: 60 – 0 kW (w/Surge Module)

60– 0 kW Step Load –Surge Module- Variable Speed

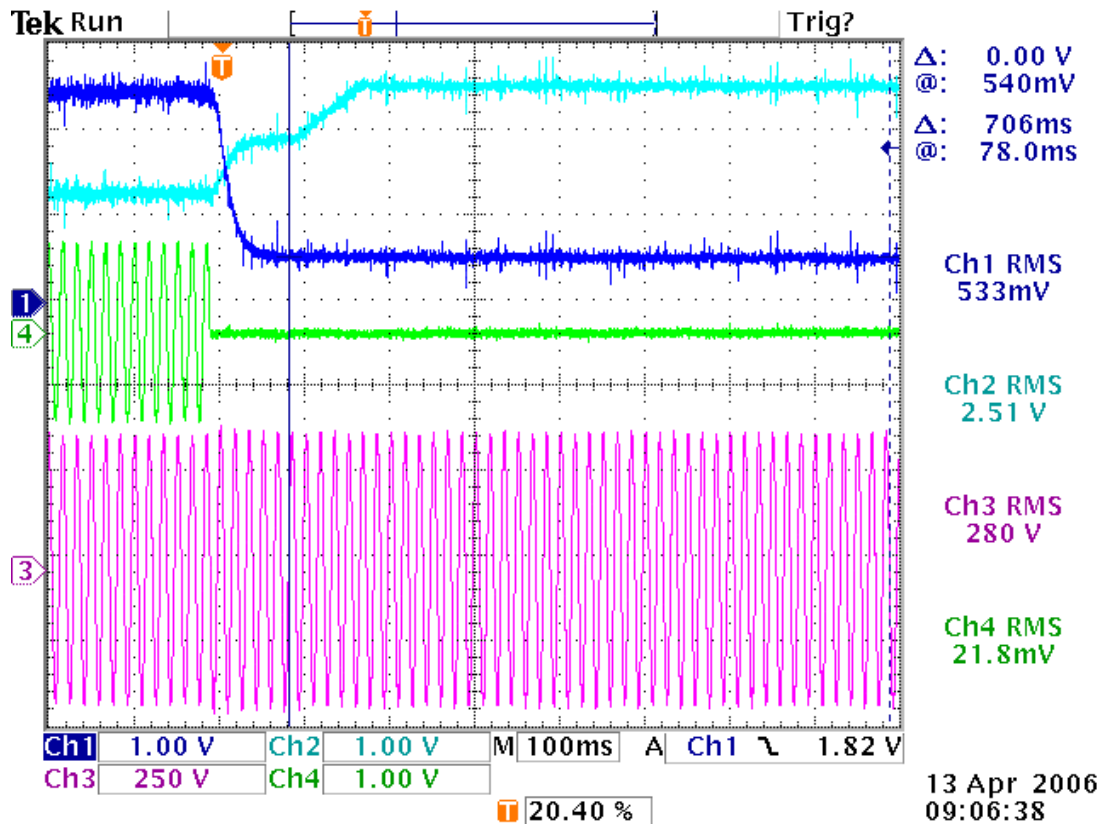


Figure 46 60 – 0 kW: Power, Frequency, Voltage, Current

v b. 55 - 0 kW (Additional test point done to ensure the frequency did not go out of range if the load slightly exceeded 60 kW from the load bank)

	A	B
Unit #1 (S.P/Actual) kW	20.0/55.8 kW	20.0/0 kW
Frequency Hz	59.70 Hz	60.16 Hz
Engine Speed (Hz/rpm)	70.1/ 2103	60/1800

Table 28 Step Load Evaluation 5b: 55 – 0 kW (w/Surge Module)

55– 0 kW Step Load –Surge Module- Variable Speed

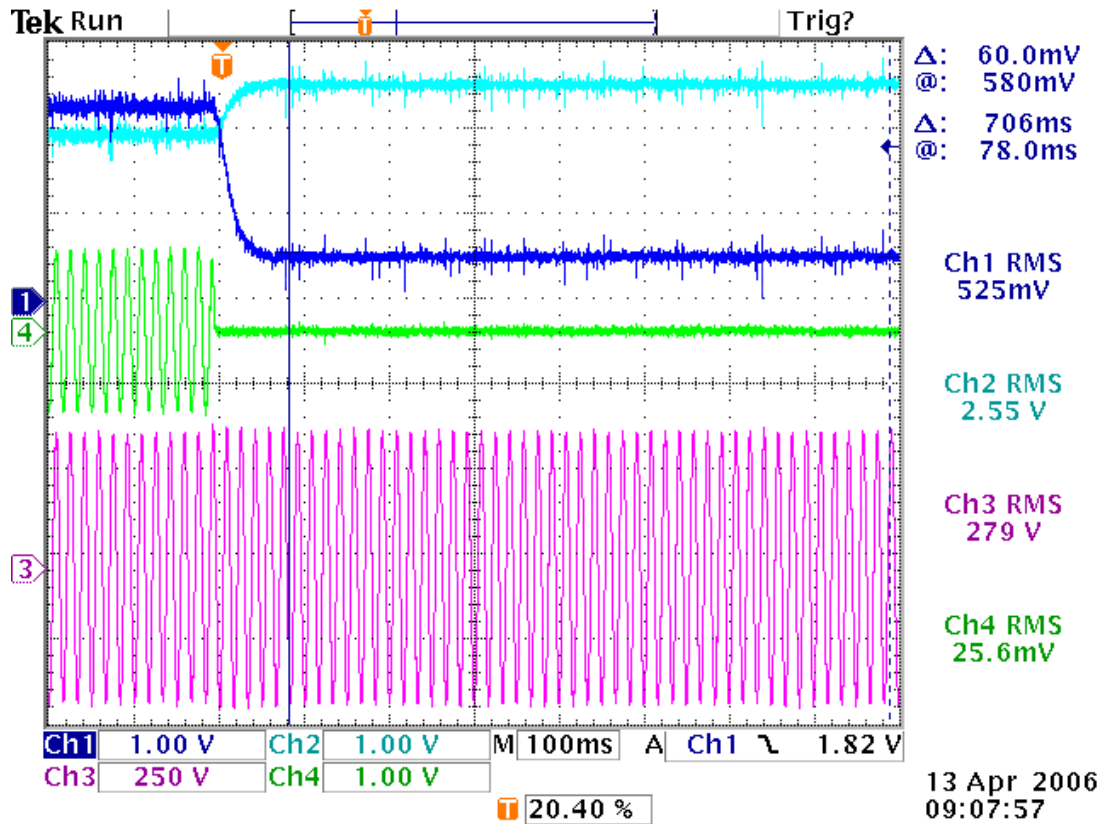


Figure 47 55 – 0 kW: Power, Frequency, Voltage, Current

vi. Step Load Evaluation 6

7. Load Bank Start Load = 30 kW
8. Unit A CMD = 20 kW
9. Load Bank End Load = 0 kW

	A	B
Unit #1 (S.P/Actual) kW	20.0/30.4 kW Unit	20.0/0 kW
Frequency Hz	59.91 Hz	60.16 Hz
Engine Speed (Hz/rpm)	60/ 1800	60/1800

Table 29 Step Load Evaluation 6: 30 – 0 kW (w/Surge Module)

30– 0 kW Step Load –Surge Module- Variable Speed

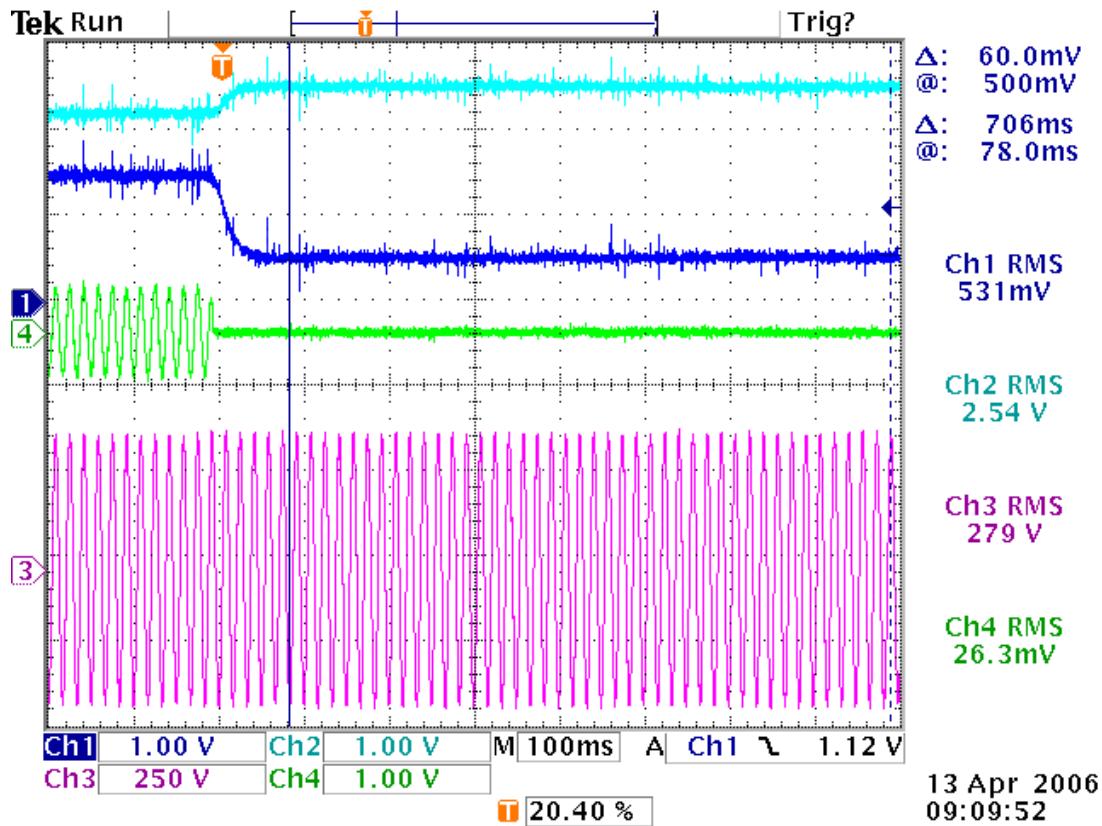


Figure 48 30 – 0 kW: Power, Frequency, Voltage, Current

B.3. Step Load Evaluations without Surge Module – Fixed Speed Operation

The CHP unit was tested with the surge module disabled. As with the first unit (Serial # 200835), the results confirmed that the dynamics of the engine/inverter allows the unit to successfully handle a step load without the surge module. The engine was set at the fixed speed required for the maximum load step of 0 – 60 kW (2160 rpm). Each step load point was run to confirm Pass/Fail. Oscilloscope data was not recorded since, as demonstrated in the testing of Unit #200835, if the unit “Passes”, the electrical output signatures (Figure 1) are the same as in Variable Speed operation.

The following table summarizes the test results.

Fixed Engine Speed 2160 rpm (72 Hz) No Surge Module		
	Step Load	Pass/Fail
i.	0 – 30 kW	Pass
ii. a	0 – 50 kW	Pass
ii. b	0 – 60 kW	Pass
iii.	15 – 50 kW	Pass
iv. a	30 – 55 kW	Pass
iv. b	30 – 60 kW	Pass
v. a	60 – 0 kW	Pass
v. b	55 – 0 kW	Pass
vi.	30 – 0 kW	Pass

Table 30 Test Point Summary – Step Loads without Surge Module/Fixed Speed